CALIFORNIA PUBLIC UTILITIES COMMISSION
ENERGY DIVISION

# RPS Calculator User Guide

## *Version 6.1*

*August 20 2015*

## Quick Start

- **How to operate the model**: Information on how operate the model and interpret model outputs can be found in the main body of this document on pages 1-10.
- **How the model works**: Detailed information on the model methodology can be found in Appendix A.
- **About the input data**: Detailed information on the model inputs and assumptions, including data sources and descriptions of the approaches used to develop data that serve as model inputs, can be found in Appendix B.

# Contents

# Model Overview

This document describes RPS Calculator version 6.1, the newest version of the model used by the Energy Division of the California Public Utilities Commission (CPUC) to develop plausible scenarios for use in the CPUC's Long-Term Procurement Planning Proceeding (LTPP) and the California Independent System Operator's (CAISO) Transmission Planning Process (TPP). The model creates plausible portfolios of renewable resources needed to meet RPS policy goals. To build a plausible portfolio, the RPS Calculator iteratively executes an annual procurement simulation in which bundles of renewable resources and transmission upgrades compete with each other to serve CAISO loads in accordance with the RPS requirement for that year. The outcome of each year's project selection process is based on the relative marginal economic value offered by each bundle of prospective resources and transmission upgrades.

The final portfolios used in LTPP and TPP are constructed of four types of resources:

1. **Existing resources:** projects online and generating renewable energy (as of a specified date).
2. **Future resources:** projects currently planned or under development, including projects with signed PPAs approved by the CPUC.
3. **Recontracted resources:** projects that are online (as of a specified date), but whose contracts expire prior to the last year of the analysis period and are selected by the model for recontracting to fill the renewable net short.
4. **Generic ("proxy") resources:** projects associated with theoretical resource potential selected by the model to fill the renewable net short.

This document serves as a user guide to the model that summarizes the contents of the model and provides an overview of the how the model constructs portfolios.

# Model Conventions

## Model Scope

With the primary purpose of developing renewable portfolios for analysis in the CAISO's biannual Transmission Planning Process (TPP) and the CPUC's Long-Term Procurement Proceeding, the RPS Calculator focuses on creating renewable portfolios for the California load-serving entities (LSEs) that are included within the CAISO balancing authority area (BAA). The compliance position of each of the IOUs' bundled customers is evaluated separately within the model. The non-IOU LSEs within the CAISO BAA (included direct access providers offering service through the IOUs' transmission and distribution networks) are included separately, as an aggregate. The calculator thus produces a portfolio of renewable resources which, for the California utilities and LSEs that reside within the CAISO BAA[1], complies with a user-specified RPS policy goal (such as 50% by 2030).

[1] See Appendix B, Table 6 for a list of LSEs included in each IOU category.

## Cost Conventions

The RPS Calculator uses a number of cost inputs to determine the appropriate ranking and selection of new renewable generation to satisfy user-specified policy goals. The current calculator uses the convention that all costs, unless otherwise specified, are expressed in 2015 dollars.

## Color Coding

The RPS Calculator uses color coding of cells and tabs to indicate the types of data contained in different cells and tabs in the model. Table 1 provides a summary of what type of information is indicated by each color.

**Table 1. Summary of general color coding in RPS Calculator.**

| Color | Description |
|---|---|
| | Inputs and assumptions |
| | Intermediate calculations |
| | Dropdown menu option |
| | Tab output/result |
| (blue text) | Data hard-coded/manipulated by macros (do not edit) |

## Table of Contents

Each tab in the RPS Calculator contains information either used to develop or summarize the portfolio. A general description of each tab is provided in Table 2.

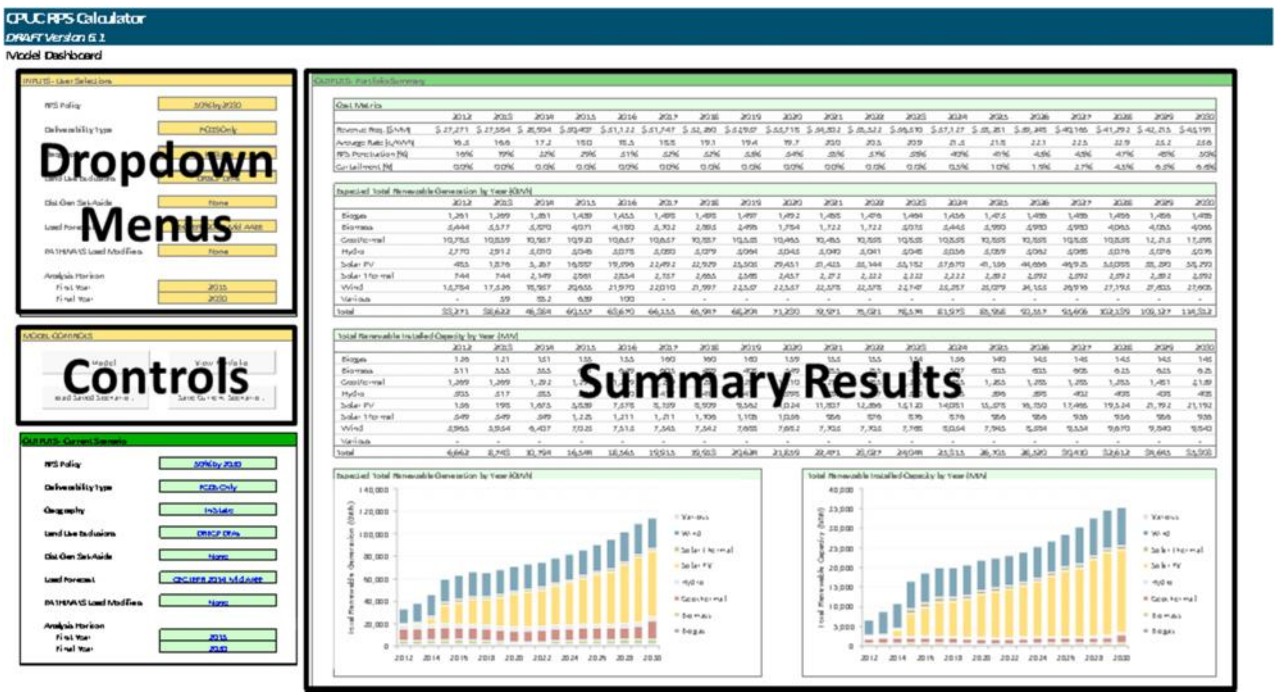
**Table 2. Description of tabs included in RPS Calculator.**

| Tab Name | | Purpose | Description |
|---|---|---|---|
| Dashboard | | User Interface | Main controls of RPS Calculator and summary of portfolio |
| Active_Portfolio | | Output | List of resources included in RPS Calculator portfolio |
| Portfolio_Analytics | | Output | Tables & graphs summarizing RPS Calculator results |
| Cost_Impacts | | Output | Approximate calculation of expected rate impacts of current portfolio |
| Supply_Curve | | Calculations | Supply curve of resources available to fill the renewable net short |
| Tx_Supply | | Calculations | Transmission cost and availability by transmission area and energy only zone |
| Util_Allocation | | Calculations | Allocation of renewable ELCC and generic capacity to each IOU and other CAISO LSEs |
| Net_Short | | Calculations | Evaluation of renewable net short for each IOU and other CAISO LSEs |
| System_Capacity | | Calculations | Determination of need for system capacity and the value of avoided capacity in each year |
| Valuation | | Calculations | Summary of 30-year forward looking energy and capacity value streams for new renewable resources |
| ELCC_Interp | | Calculations | Calculation of marginal ELCCs for various technologies |
| Energy | | Calculations | Calculation of total production value associated with candidate renewable resources |
| Dispatch_Curve | | Calculations | Calculation of thermal 'stack' of dispatchable generators used to value energy production of renewables |
| Resource_Cost | | Calculations | Vintaged cost-based PPA prices reflecting changes to financing, tax benefits, and technology costs over time |
| Pro_Forma | | Calculations | Cash flow model used to evaluate cost-based PPAs for resources based on cost & performance inputs |
| Storage_Inputs | | Inputs | Calculation of available incremental storage resources used in production value analysis |
| Hydro_Param | | Inputs | Calculation of the constraints applied to hydro generation and its relationship to net load |
| Load_Shape | | Inputs | Calculation of load shape accounting for PATHWAYS load modifiers |
| Env_Screen | | Inputs | Input table specifying the discount applied to generic resources for each environmental screen |
| Specified_Adds | | Inputs | User-controlled input table for model that allows user to specify resources to include in a portfolio |
| Load_Forecast | | Inputs | Annual forecasts of system peak demand, net energy for load, and retail sales |
| Generators | | Inputs | List of non-renewable generators in the CAISO system/contracted to CAISO LSEs |
| General_Inputs | | Inputs | Additional general input parameters |
| RPS_Policy | | Inputs | Inputs related to the choice of an RPS policy |
| ELCC_Table | | Inputs | Table of total ELCCs provided by various renewable portfolios based on ELCC model runs |
| Resource_Char | | Inputs | Resource cost and performance inputs |
| CAISO_Tx_Inputs | | Inputs | Transmission cost and availability provided by CAISO for transmission areas and energy only zones |
| CREZ_Tx_Inputs | | Inputs | Conceptual transmission inputs |
| Tx_Mapping | | Inputs | Mapping of CREZ/WREZ areas to transmission areas, and transmission areas to energy only zones |
| Batch | | Back-end | Controls for multiple scenarios |
| Storage | | Back-end | Saved inputs from most recent update to renewable PPA prices |
| Controls | | Back-end | Lookup tables and ranges for dropdowns and data validation *(not meant for user interaction)* |
| Input_Index | | Back-end | Description and links to key inputs throughout model |

# Model Dashboard & General Model Operations

The ‘Dashboard’ tab of the RPS Calculator serves as the primary user interface for operating the model. It allows users to select the assumptions that will guide the model’s choice of renewable resources to meet a policy target and to run the model to create a renewable resource portfolio based on those assumptions. It also provides a summary of the constituent resources included in the current portfolio by resource type and by location. A screenshot of the ‘Dashboard’ is shown in Figure 1.

**Figure 1. Screenshot of RPS Calculator Dashboard.**




When the user first opens the RPS Calculator, the Dashboard reflects the portfolio of renewable resources that was generated the last time the model was run and saved. Each time the model is run, the portfolio is reset to a base set of renewable resources that reflects the existing resource procurement of IOUs and public utilities served in the CAISO. This set of resources includes projects currently online (“existing resources”) and future planned projects (“future resources”) whose generation potential has been derated to account for the risk that the project will not be developed.[2,3] This base set of resources is typically not sufficient to meet the user-specific RPS policy goal, unless the goal is set relatively low (e.g., lower than 33%).

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[2] The existing and future resources in v.6.1 of the RPS Calculator is based on information submitted by the IOUs to the CPUC through April 2015; projects online prior to May 1, 2015 are classified as “existing,” whereas those that had not achieved operations by that date are classified as “future.”

[3] The risk adjustment occurs at the portfolio level: it is assumed that 84% of planning projects will succeed, so output from all IOU planned projects is derated by 16% in the calculation of each utility’s compliance position and renewable net short.

## Running the Model

To run the RPS Calculator, the user selects a set of assumptions from the 'Inputs' section of the Dashboard. This section of the dashboard contains a number of dropdown menus that allow the user to select the assumptions that will shape how the RPS Calculator ranks and selects resources. The options for user inputs are summarized in Table 3.

Once the user has selected the desired set of input assumptions, the user may run the model by clicking the 'Run Model' button in the Controls box, which triggers the model's resource selection algorithm. The RPS Calculator's selection engine runs through a macro that selects resources in each year to meet policy targets subject to the user-defined constraints; while the model is running, the dashboard will update the user with the model's progress. The user can also monitor the progress of the model on Excel's status bar:

**Figure 2. Status bar indication of model progress.**


Because the Calculator will require multiple recalculations throughout a model run as it evaluates the changing costs and values of renewable generation through time, the model will run most quickly when other Excel workbooks are closed. Model runtime may vary considerably with input assumptions, the type of computer used to run the model, and the number of other open applications, but users should generally anticipate runtimes between five and twenty minutes for each scenario.

## Viewing Model Results

The calculator will indicate its completion of a modeling run with a dialog box. At this point, the Dashboard will display a complete summary of the portfolio selected to meet the stated policy goals and procurement preferences.

### Active Portfolio

To see the resources that make up the portfolio, the user can navigate to the 'Active_Portfolio' tab (either manually or by clicking the 'View Portfolio' button) to see a detailed line-item summary of all the renewable generation that has been included in the portfolio. The 'Active_Portfolio' tab displays all of the renewable resources assumed to contribute to the renewable policy goals of LSEs within the CAISO.

### Table 3. Guide to Dashboard dropdown menu options

| Dropdown Menu | Dropdown Option | Description |
|---|---|---|
| **RPS Policy** | 33% by 2030 | Achieves a 33% RPS by 2020 and maintains that level thereafter |
| | 40% by 2030 | Achieves a 33% RPS by 2020 and a 40% RPS by 2030 |
| | 50% by 2030 | Achieves a 33% RPS by 2020 and a 50% RPS by 2030 |
| **Deliverability Type** | FCDS Only | Assigns FCDS status to all projects. Triggers transmission upgrades, if needed, for all projects. No EO projects. |
| | FCDS & EO | Triggers transmission upgrades and assigns FCDS status only when including the upgrade is more economical than not including it. Otherwise, assigns EO status. |
| | FCDS & EO (No New Tx) | Prohibits all transmission upgrades. Assigns FCDS status only to projects selected in areas where existing transmission capacity is already available. Otherwise, assigns EO status. |
| **Portfolio Geography** | In-State | Builds portfolio by selecting from among potential generic projects located in the state of California |
| | WECC-Wide | Builds portfolio by selecting from among potential generic projects throughout the WECC |
| **Land Use Exclusions** | Base | Excludes resource potential associated with land meeting certain technological restrictions and/or in RETI Category 1. |
| | Env Baseline | Excludes resource potential associated with land meeting certain technological restrictions and/or in RETI Category 1 and/or in RETI Category 2. |
| | DRECP DFAs | Excludes resource potential associated with land meeting certain technological restrictions and/or in RETI Category 1 and/or in RETI Category 2; for land in DRECP, also excludes land outside of Development Focus Areas (DFAs). |
| **Dist Gen Set-Aside** | None | Selects wholesale DG only when its net value is higher than all other potential projects. |
| | 15% of substation load | Automatically selects a minimum amount of DG PV resources sufficient to achieve 15% penetration of each substation's minimum daytime load. |
| | 30% of substation load | Automatically selects a minimum amount of DG PV resources sufficient to achieve 30% penetration of each substation's minimum daytime load. |
| | 100% of substation load | Automatically selects a minimum amount of DG PV resources sufficient to achieve 100% penetration of each substation's minimum daytime load. |
| **PATHWAYS Load Modifiers** | None | Reference load scenario; no modifications to the level of load beyond what the user has specified in the Load Forecast; no change in load shape relative to historical. |
| | Straight Line | Includes impacts of incremental EE and electrification of buildings and vehicles; also includes new flexible loads needed to produce decarbonized fuels. |
| | High BEV | Includes impacts of a transition to battery electric vehicles |
| | Low Carbon Gas | Includes limited incremental EE/electrification, includes large additional flexible load needed to produce decarbonized pipeline gas |
| **Load Forecast** | CEC IEPR 2014 Mid AAEE | Load forecast based on CEC's 2014 IEPR study including the impacts of incremental energy efficiency |
| | CEC IEPR 2014 Mid No AAEE | Load forecast based on CEC's 2014 IEPR study excluding the impacts of incremental energy efficiency |

Once the model has been run, the detailed composition of the resulting portfolio is contained entirely on the 'Active_Portfolio' tab. The Active Portfolio contains all projects ever selected to serve load at any point before or during the analysis period. In some cases, a project may appear more than once in the portfolio. For example, a project that was online at the beginning of the analysis period will re-appear if its contract expires and it is selected to receive another contract. Without additional sorting, the user can develop a basic understanding of how a portfolio was built year by year by scrolling through the portfolio and inspecting the contract start dates. To view projects that are online as of a certain year, the user can filter projects based on the contract start and end dates.

All data on the 'Active_Portfolio' tab is hard-coded; the model's selection algorithm selects the most favorably ranked resources in each year and adds them to the active portfolio through a macro-based routine. Table 4 summarizes the contents of the 'Active_Portfolio' tab.

**Table 4. Summary of data fields included in Active_Portfolio tab.**

| Column | Field | Units/Type | Description |
|---|---|---|---|
| A | Index | Integer | Line item ID |
| B | Category | Integer<br>[1/2/3/4] | Indicator of procurement 'category':<br>1: Existing resource<br>2: Future resources<br>3: Recontracted resource<br>4: Generic (proxy) resource |
| C | Project ID | Text field | Unique project ID where applicable |
| D | Project Name | Text field | Name associated with project |
| E | State | Text field | State in which project is located |
| F | County | Text field | County is which project is located |
| G | Electrical Zone | Text field | SuperCREZ/WREZ in which project is located |
| H | Latitude | Number | Project latitude (where applicable) |
| I | Longitude | Number | Project longitude (where applicable) |
| J | LCR Area | Text field | |
| K | Technology | Text field | Generation technology |
| L | Subtechnology | Text field | Generation subtechnology |
| M | Development Status | Text field | Flag for existing/new projects |
| N | Contract Start Date | Date | Assumed date of contract start |
| O | Contract End Date | Date | Assumed date of contract expiration |
| P | Eligible for Recontracting | [0/1] | Flag for projects to allow/prohibit recontracting upon contract expiration (1 by default) |
| Q | Product Content Category | [0/1/2/3] | Product content category as defined by the CPUC:<br>0: Pre-June 1, 2010<br>1: Category 1<br>2: Category 2<br>3: Category 3 |
| R | CAISO | [0/1] | Flag for point of interconnection relative to CAISO<br>0: Outside CAISO<br>1: Inside CAISO |
| S | Bundled | [0/1] | |
| T | Deliverability | [0/1] | Deliverability status:<br>0: Energy only (EO)<br>1: Full capacity deliverability status (FCDS) |
| U-X | LSE Allocation | % | Allocation of original contracted volumes to LSEs (PG&E, SCE, and SDG&E bundled customers; other CAISO ratepayers) |
| Y | Contract Capacity | MW | Expected nameplate capacity of generation facility |
| Z | Annual Energy | GWh | Annual expected generation produced by project |

| | | | |
|---|---|---|---|
| AA | Capacity Factor | % | Annual expected capacity factor |
| AB | Technology Index | Integer [1-19] | Look-up index for technology/subtechnology pairing |
| AC | ELCC Valuation Profile | Text field | Text field with limited options |
| AD | Energy Valuation Profile | Text field | Text field with limited options |
| AE | Losses | % | Incremental losses (% of generation) |
| AF | Risk Adjustment | % | Risk adjustment factor used to derate project output (GWh) for future projects in order to reflect their probability of failure |
| AG | Unit Cost | $/MWh | Assumed PPA price of renewable resource |

## Portfolio Analytics

In addition to the summary outputs shown on the Dashboard, users can view a more detailed summary of model outputs on the 'Portfolio_Analytics' tab. This tab contains a number of graphs and tables that provide further insight into the impacts of the portfolio on the electric system. Specific information that a user can find on this tab includes:

- Breakdown of installed capacity by CREZ & technology;
- Geographic locations of California resources in the specified portfolio;
- Utilization of existing transmission capacity and transmission upgrades triggered by the portfolio;
- Composition of portfolio (existing, future, recontracted, and generic resources) by year;
- Composition of portfolio (full capacity and energy only resources) by year;
- Fractions of generic potential (geothermal, solar PV, wind) selected by CREZ/WREZ; and
- Summary of net load and overgeneration patterns given the renewable buildout.

## Cost Impacts

The cost impact of a given portfolio on the IOUs' ratepayers is shown on the 'Cost_Impacts' tab, which calculates a forecast of each utility's bundled revenue requirement and average retail rate based on the characteristics of the renewable resources included in the portfolio. The revenue requirement calculation comprises costs in four broad categories:

- **Distribution:** costs related to the investment in and maintenance of the distribution system (largely independent of the renewable portfolio).
- **Transmission:** costs related to the investment in and maintenance of the transmission infrastructure, including new transmission build triggered by the renewable generation in a given portfolio.
- **Generation:** costs of all energy and capacity needed to serve load reliably across the year, including:
  - Rate base and variable costs of utility-owned generation assets;
  - PPAs with renewable generators; and
  - Wholesale purchases and long-term contracts for energy and capacity.
- **Other:** costs of demand-side management (DSM) programs, bonds, and franchise fees (independent of the renewable portfolio).

The aggregate revenue requirement and average rate for the three utilities together are also shown on the 'Dashboard' tab for each year in the modeling horizon.

## Saving a Scenario

The RPS Calculator allows users to save the resulting portfolio of a model run to an external file to allow for later viewing. After running the model to create a portfolio given a set of assumptions, the user should click the 'Save Current Scenario…' button on the Dashboard. Clicking this button will open a dialog box prompting the user to enter a name for the scenario; after entering a name, click 'OK' to save the scenario. The RPS Calculator will save the scenario in a comma-separated value (CSV) file that contains the user's dropdown selections from the Dashboard as well as the contents of the 'Active_Portfolio' tab. By default, this CSV file will be stored in a folder named "[*Model Name*]_Results" located within the same folder where the user has saved the Calculator.

## Loading a Scenario

Once a user has run and saved a scenario using the 'Save Current Scenario…' functionality, that scenario can be loaded back into the RPS Calculator to view summary results. To retrieve a saved scenario, the user should click the 'Load Saved Scenario…' button on the Dashboard, which will prompt the user to specify a file to load into the calculator (scenarios saved using the Calculator functionality will be located in a folder named "[*Model Name*]_Results" at the same location as the model itself).

This functionality also allows users of the same version of the model to share outputs easily. Once a scenario has been run and saved by a single user, that CSV file can be shared with other users, who can load the results into their respective models in order to inspect the results. Only scenarios created by the same RPS Calculator version can be accurately loaded and viewed. Scenarios created with version 6.0 of the RPS Calculator should not be loaded into version 6.1.

# Advanced Operations

## Other Model Inputs

The Dashboard is intended to provide the user's main point of interaction with the RPS Calculator, allowing the user to specify key model assumptions to define the scenario to be modeled. However, many additional input assumptions are located throughout the other tabs of the model, and users may wish to investigate the impact of altering other assumptions on the result of the portfolio. In order to facilitate this process, the 'Input_Index' tab provides hyperlinks to the other model inputs, as well as a brief description of their role and origin as well as references to any key data sources.

## Batch Scenario Runs

The RPS Calculator includes a batching function to sequentially model up to 20 pre-defined scenarios and save the resulting portfolios for later inspection and comparative analysis. To run a batch of scenarios, the user must specify a name and set of input assumptions for each scenario to be modeled using the 'Batch' tab. Only the primary input assumptions listed on the Dashboard may be specified in batch runs. After specifying the desired scenario names and input assumptions, the batch can be initiated by clicking the “Run Batch Scenarios” button. The results of each scenario will be saved as a separate CSV file as described under the section “Saving a Scenario” above.

# Appendix A. RPS Calculator Model Methodology

This appendix provides additional information on the methodology used in the RPS Calculator to develop renewable resource portfolios. The first section of this appendix provides an overview of the modeling framework. Following the overview, individual components of the methodology are described in greater detail. For more information on the input data and assumptions, please see Appendix B.

## Methodology Overview

The RPS Calculator builds renewable portfolios using an iterative, stepwise process to select generic renewable resources and potential transmission upgrades needed to meet a user-defined RPS target. First, the renewable net short for the first year of the analysis period is calculated by measuring the difference between that year's RPS compliance requirement and the available generation from the base set of renewable resources already procured. The compliance requirement is based on the RPS policy goal and load forecast options selected by the user. The base set of renewable resources already procured includes existing resources currently in operation ("existing resources") and planned resources under contract to utilities that have not yet come online ("future resources").

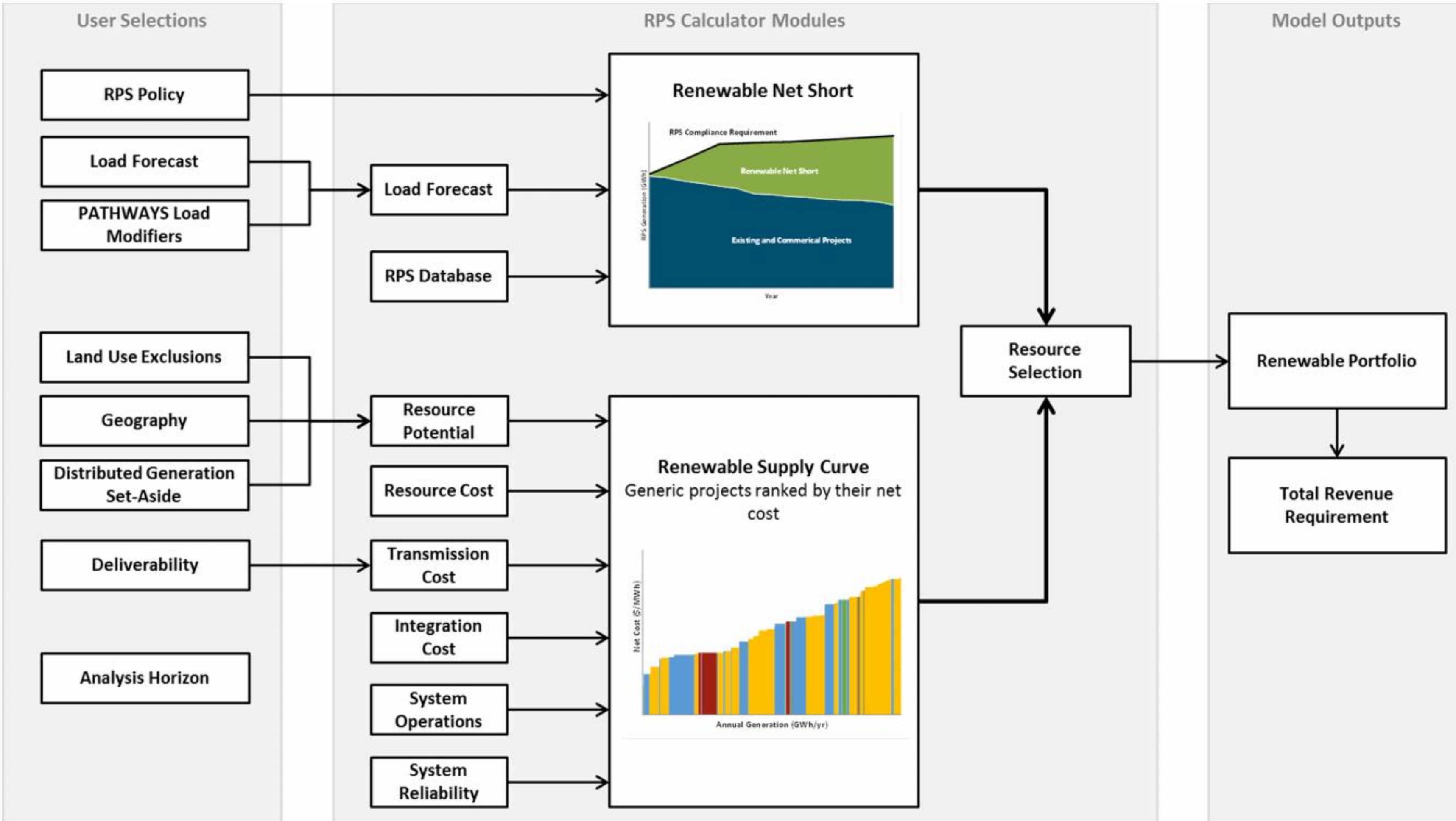
Next, a large set of potential renewable resources located throughout California and the WECC region ("generic" or "proxy" resources) are evaluated using a calculation that aggregates a suite of different cost and value elements. The cost and value elements in the RPS Calculator are similar to those in the Net Market Value (NMV) formula used in the "least cost, best fit" (LCBF) evaluation process required for actual procurement in the Commission's RPS proceeding.[4] The NMV of each generic renewable resource is calculated as the sum of the following components: (a) resource cost; (b) transmission cost; (c) integration cost; (d) curtailment cost; (e) energy value; and (f) capacity value. The value of each of these elements for each resource changes over time due to technological innovation, financing and tax policies and portfolio saturation effects. A supply curve of renewable resources is developed by ranking each of the generic projects by their NMV, accounting for resource potential limitations, including land use exclusions, geographic limits and DG set-asides, as well as the availability of transmission.

Finally, the least-cost resources are selected from the renewable supply curve to the fill the renewable net short. The resource selection process occurs in each year of the simulation, and the process is iterative – the order of resources in the supply curve adjusts each year as the renewable resource mix changes.

Figure 3 outlines the modeling framework described above.

[4] The LCBF is implemented slightly differently by each IOU, and each IOU's approach is slightly different than that taken in the RPS Calculator.

**Figure 3. Organization of RPS Calculator.**



## Load

The load forecast assumed for each of the utilities is a fundamental driver of the amount of renewable generation needed to comply with policy goals and is also a secondary driver of the relative value of different renewable generation technologies.

Load forecast data, and related calculations, are stored in the "Load_Forecast" tab. A load forecast comprises multiple assumptions, including:

- Anticipated levels of load growth;
- Deployment of incremental energy efficiency;
- Adoptions of customer-sited, behind-the-meter solar PV; and
- Electrification of end uses currently served by non-electric fuels.

Additional information on the sources of data and calculations used to develop the load forecast and load shapes used in the RPS Calculator are included in Appendix B.

The resulting load forecast flows into several other modules in the RPS Calculator, impacting the results of the calculator both directly and indirectly:

- The load forecast has a direct impact on the portfolio through its impact on the Renewable Net Short calculation: because the RPS policy goal is expressed as a percentage of retail sales, the load forecast establishes the total size (in GWh) of the renewable portfolio needed to comply with a specified goal.
- The load forecast indirectly impacts the portfolio through its impact on energy value, curtailment cost, and capacity value.[5] All three of these components of the NMV calculation are determined by comparing the renewable portfolio against load to determine the marginal impacts. Thus, both the load itself, as well as the assumptions embedded within it regarding the penetration of behind-the-meter solar PV installed over time, impact the valuation—and consequent selection—of the renewable resources within the Calculator.

## Renewable Net Short

The Renewable Net Short (RNS) is a measure of the incremental amount of renewable generation needed beyond those resources already under contract to a utility (existing and future resources) in order to comply with a specified RPS policy goal. The RPS Calculator evaluates the RNS for each IOU (as well as for an aggregation of the other retail loads of the CAISO) in order to determine how much additional generation should be selected by the Calculator to create a plausible portfolio consistent with the user-specified policy goal. The Renewable Net Short is calculated on the "Net_Short" tab.

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[5] The role of load shapes in influencing capacity value is discussed in more detail in the section "System Reliability." The role of load shapes in influencing energy value and curtailment cost is discussed in more detail in the section "System Operations."

The RNS calculation also accounts for flexible compliance, tracking each utility's banked RECs. Each year in which a utility has a surplus of renewable generation under contract relative to the policy target, the surplus is assumed to accrue in a bank. In reality, each utility's strategy to use these RECs to meet compliance obligations in future years is confidential; absent this information, the Calculator uses a simple rule-of-thumb that spreads banked renewable generation across a ten-year period to reduce the RNS and defer future procurement (e.g. 10 GWh of banked generation would be redeemed in 1 GWh increments across a ten-year period). The assumed period across which banked generation is redeemed may be modified by the user on the 'RPS_Policy' tab.

## Resource Potential

The renewable resource potential is evaluated using an NMV approach to generate a supply curve. The supply curve consists of a ranked set of potential renewable resources that are used to fill the RNS.

Resource potential data are stored in the "Supply_Curve" tab. Each candidate resource is characterized based on its location, raw resource potential (capacity, MW), expected performance (capacity factor, %), and cost (expressed as a set of multipliers relative to average technology costs, %).

Additional detail on the development of the resource potential estimates is included in Appendix B.

### Environmental Screens

Not all lands are suitable for renewable energy project development. The RPS Calculator has the ability to constrain the resource potential used to fill the Renewable Net Short to account for restrictions on land use. The model implements this functionality by including a set of up to six alternative multipliers to discount the potential for each resource. The option selected from the "Land Use Exclusions" dropdown menu on the Dashboard dictates which of the alternative sets of multipliers is used for each resource in the supply curve.

The alternative multipliers for each potential renewable resource can be viewed and set using "Env_Screen" tab. The land-use based discount applied to any given resource for the current Dashboard option can be seen in the tab "Supply_Curve", in the column "Multiplier – Land Use Screen".

Additional detail on the screens used to produce the resource potential values included in the "Env_Screen" tab is included in Appendix B.

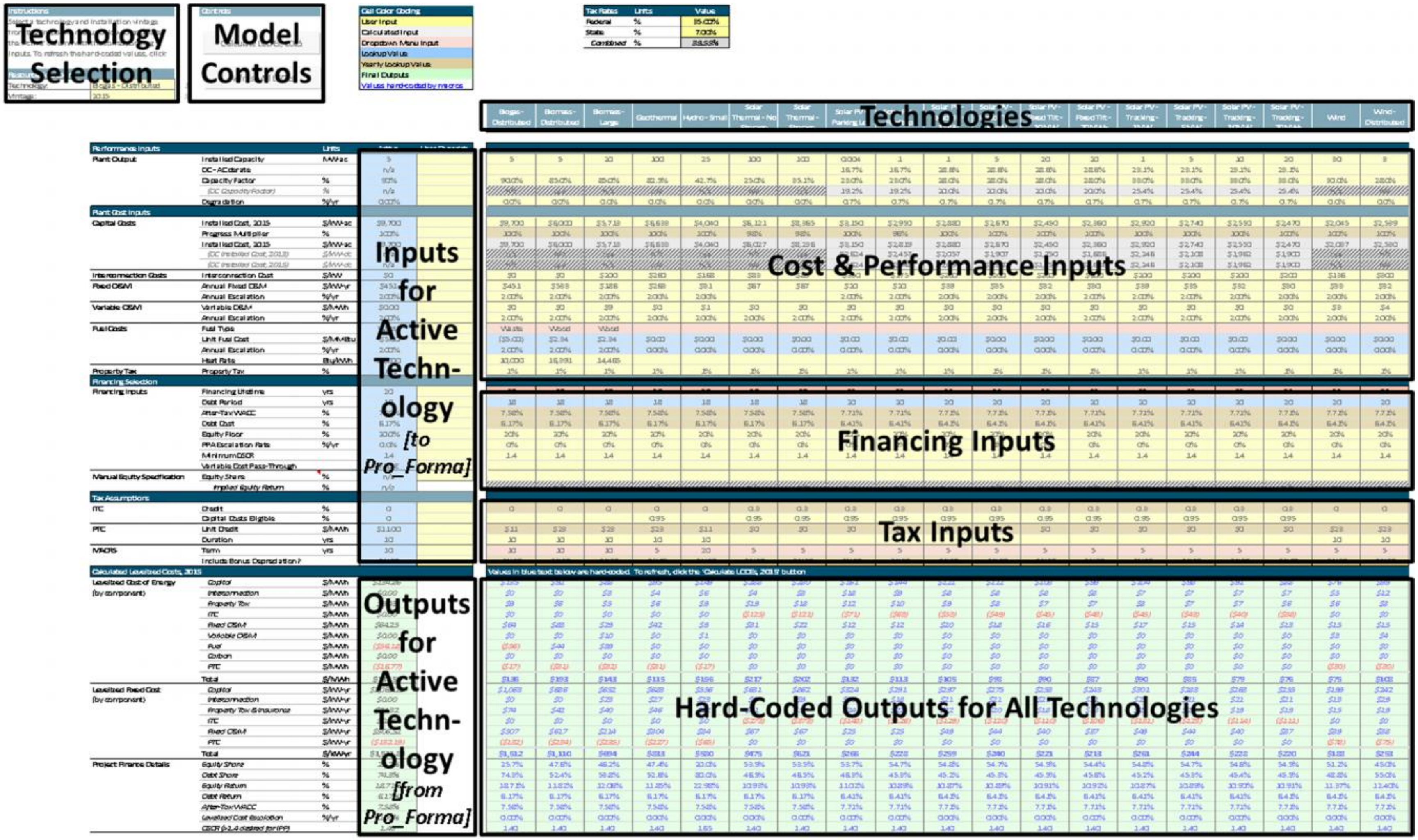
## Resource Cost

The Resource Cost module in the RPS Calculator estimates PPA prices for future renewable contracts given assumptions on the future cost, financing structure, and tax incentives of renewable projects. PPA prices are calculated using a pro-forma cash flow model that mimics the structure of a PPA between a developer and a credit-worthy utility. PPA prices for each resource are calculated to provide developers with sufficient return of and on capital over the lifecycle of the project in order to allow investment. This module comprises three primary tabs in the RPS Calculator:

- **Resource_Char:** input assumptions for the cost, performance, financing, and tax treatment of new generation technologies (shown in Figure 4).
- **Pro_Forma:** a cash-flow financing model that calculates a levelized cost of energy based on a single set of input assumptions for a single generation resource as a proxy for a cost-based PPA.
- **Resource_Cost:** look-up tables for levelized cost of energy (LCOE) components by technology and installation vintage.

The Resource Cost module operates as a standalone model within the RPS Calculator: that is, the input assumptions on the 'Resource_Char' tab are iteratively fed through the 'Pro_Forma' one at a time, and results are stored in the 'Resource_Cost' tab. This looping process can be activated by the user by clicking the 'Refresh All LCOEs' button on the 'Resource_Char' tab.

**Figure 4. Screenshot of resource cost module used to derive cost-based PPA prices.**



A number of the assumptions that determine resource costs will vary depending on the year in which a project is installed. To account for the evolving nature of resource costs, the 'Resource_Char' tab also contains year-by-year input assumptions (shown in Figure 4 in the golden cells) for each of these parameters below the table in which the input assumptions are shown.

The inputs used to derive cost-based PPAs for future renewable contracts fall into three categories:

1. **Cost & performance inputs**: assumptions relating to the costs of constructing and operating a renewable generation facility; developed by Black & Veatch.
2. **Financing inputs**: assumptions relating to the structure of project finance used to develop a project; developed by E3.
3. **Tax inputs**: assumptions regarding the availability of federal tax credits and benefits available to renewable projects; based on current federal policy.

Any of these inputs can be updated by a user of the RPS Calculator to test the impact of an alternative assumption on the portfolio results. Because the Resource Cost module relies on a macro to calculate PPA prices for each technology and installation vintage iteratively, the user must refresh the stored PPA costs after updating an input assumption. This can be achieved by clicking the 'Refresh All LCOEs' button on the 'Resource_Char' tab.

Additional detail on the source of the assumptions used to develop resource cost estimates is provided in Appendix B.

## System Reliability

The System Reliability module is used to calculate the marginal capacity value provided by potential new renewable resources.[6] The capacity value ascribed to each renewable resource is calculated as the product of two terms: (1) its marginal effective load carrying capability (ELCC), expressed as a percentage of nameplate capacity; and (2) the avoided cost of system RA capacity. Both values change over time with changes in the composition of the generation fleet (both renewable and non-renewable) as well as changes in load.

### Renewable ELCC

The RPS Calculator uses "effective load carrying capability" (ELCC) to measure the contribution of renewable resources towards system reliability. For a given resource, the ELCC is defined as the incremental flat load that may be met when that resource is added to a system while preserving the same level of reliability. ELCC is commonly derived through loss-of-load-probability (LOLP) modeling frameworks. It is a portfolio attribute; that is, the ELCC of a given renewable resource can be highly sensitive to other resources on the system due to interactive effects.

[6] Resources that are selected with an energy only deliverability status are assigned a capacity value of 0.plann

The RPS Calculator incorporates results of E3's Renewable Energy Capacity Planning (RECAP) model[7] in order to evaluate the marginal ELCC of wind and solar resources at different penetrations considered within the calculator. The RECAP model was used to generate a lookup table of cumulative system ELCC (expressed as a percentage of 1-in-2 peak demand) as a function of the penetration of different wind and solar resources (expressed as a percentage of net energy to load). The results of nearly 10,000 runs of the RECAP model are contained on the 'ELCC_Table' tab (see Figure 5) and are used to interpolate marginal ELCCs of wind and solar resources at relevant penetrations of wind and solar in the Calculator.

**Figure 5. Normalized table of ELCC values used to evaluate wind & solar marginal ELCC values.**

| ID | CSP - No Storage | CSP - Storage | Solar PV - Dist | Solar PV - Utility | Wind - Coastal | Wind - Inland | Cumulative ELCC (% of Peak |
|---|---|---|---|---|---|---|---|
| 1 | - | - | - | - | - | - | - |
| 2 | - | - | 0.030 | - | - | - | 0.045 |
| 3 | - | - | 0.060 | - | - | - | 0.082 |
| 4 | - | - | 0.090 | - | - | - | 0.107 |
| 5 | - | - | 0.120 | - | - | - | 0.120 |
| 6 | - | - | - | 0.015 | - | - | 0.018 |
| ⋮ | | | ⋮ | | | | ⋮ |
| 9745 | 0.030 | 0.015 | 0.120 | 0.165 | 0.100 | 0.050 | 0.221 |
| 9746 | 0.030 | 0.015 | - | 0.180 | 0.100 | 0.050 | 0.216 |
| 9747 | 0.030 | 0.015 | 0.030 | 0.180 | 0.100 | 0.050 | 0.219 |
| 9748 | 0.030 | 0.015 | 0.060 | 0.180 | 0.100 | 0.050 | 0.220 |
| 9749 | 0.030 | 0.015 | 0.090 | 0.180 | 0.100 | 0.050 | 0.221 |
| 9750 | 0.030 | 0.015 | 0.120 | 0.180 | 0.100 | 0.050 | 0.221 |

## Avoided Cost of Capacity

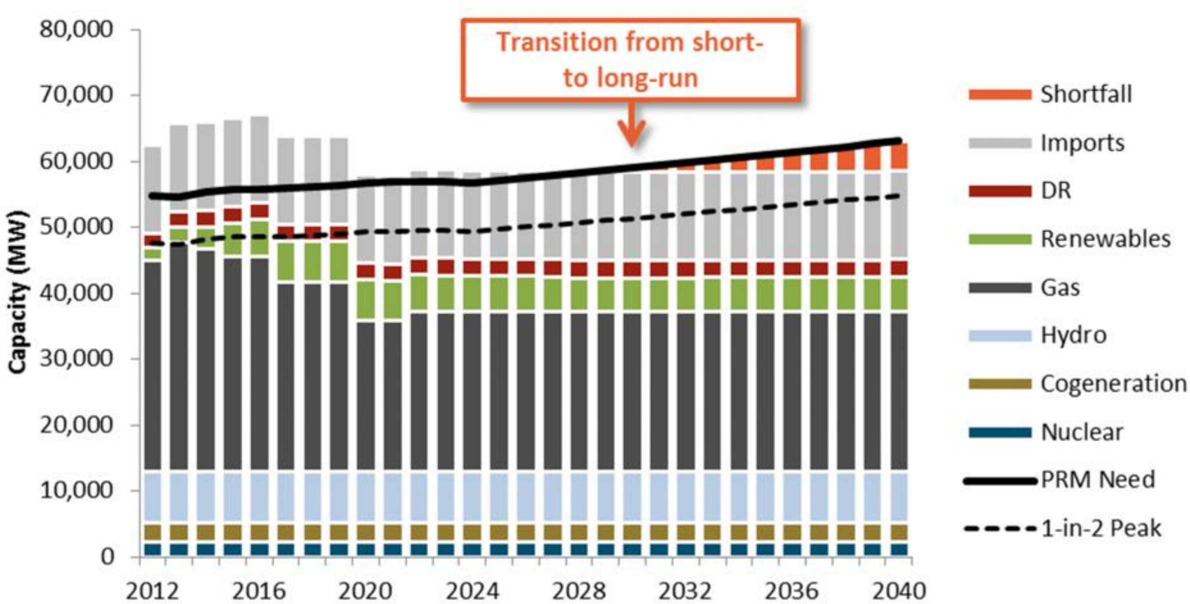
The second component of the capacity value attributed to renewable resources is the avoided cost of capacity, intended to represent the cost of the marginal resource that a utility would otherwise procure to meet system resource adequacy requirements in each year. The avoided cost of capacity is linked to the system's reserve margin: when the projected reserve margin exceeds the minimum reliability threshold of a 15% planning reserve margin (PRM), the avoided cost is based on the cost of contracting for RA capacity with an existing generator ("short-run" avoided cost); when the projected reserve margin falls below this threshold, the deficit is assumed to be met with investment in new combustion turbines (CT) such that the avoided cost of capacity is based on the net cost of new entry of a new CT ("long-run" avoided cost).

[7] For more information on RECAP, see http://ethree.com/public_projects/recap.php.

**Figure 6. Short- and long-run avoided capacity costs assumed in the RPS Calculator.**

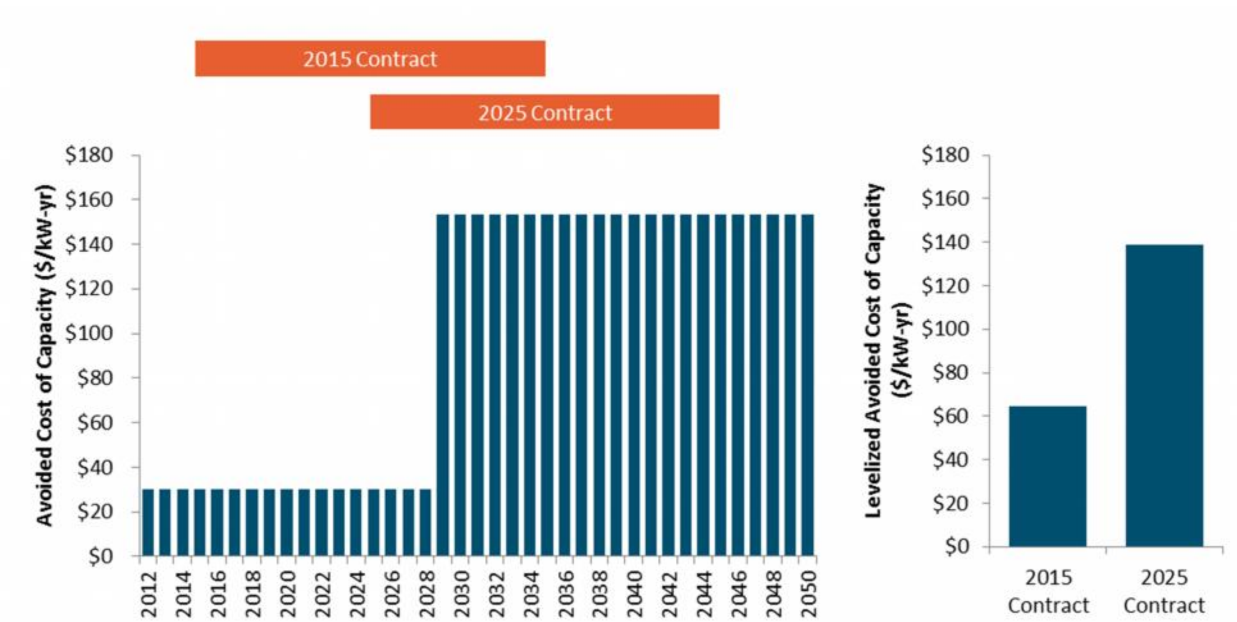

The system's reserve margin is projected for each year in the analysis horizon (2012-2060) in order to attribute a short- or long-run avoided cost to system capacity. The contribution of non-renewable resources (nuclear, cogeneration, hydro, gas, demand response, and imports) towards the CAISO PRM is based on the LTPP's standard planning assumptions; the contribution of renewable resources to the PRM is calculated in the RPS Calculator by estimating the total ELCC of the renewable portfolio using the surfaces described above. Figure 7 shows an illustrative projection of the CAISO's load resource balance.

**Figure 7. Illustrative projection of system capacity balance, 2012-2040**



To calculate the capacity value for each prospective renewable resource, the RPS Calculator determines the levelized avoided cost of capacity across the lifetime of each prospective new contract. Because it calculates the avoided cost across the lifetime of the project, in each successive year the Calculator assigns a capacity value that is closer and closer to the long-run avoided cost. As an example, Figure 8 illustrates how contracts signed ten years apart are attributed different avoided capacity costs based on the stream of avoided costs over their respective lifetimes.

**Figure 8. Examples of levelized avoided capacity costs over contract lifetimes.**




## System Operations

The RPS Calculator uses a stack model to evaluate the marginal energy value and marginal curtailment of prospective renewable resources. The model approximates the dispatch of California resources to serve load in each of 288 periods (an average hour of each day for each month, or month-hour) throughout each year in the time horizon considered in the RPS Calculator (2012-2060). In this respect, the operations module approximates the average hourly dispatch of generation to serve load that would be expected in each month of the year. Marginal energy value is calculated based on the short-run avoided cost of the marginal gas resource used to serve load in each of the periods; marginal curtailment is calculated based on the frequency of periods in which all generation resources are operating at minimum levels while total generation exceeds load.

### Load Shapes

The load shape is the temporal pattern of electricity usage over the day and throughout the year aggregated across the entire CAISO system. The load shape is used to calculate the CAISO system load, and, along with resource capacities and shapes, the “net load” for each average month-hour. To calculate the system load in each period of the year, the operations module multiplies the total annual load derived from the load forecast data by a load shape derived from historical CAISO data.

In the RPS Calculator, the load shape is composed of a set of values, each of which represents the percentage of total annual energy use that occurs in that period. The sum of all values comprising the load shape is 100%. The historical load shape is assumed to remain constant into the future (i.e. impacts of energy efficiency and electrification embedded in the load shape are not assumed to alter the shape of load substantially).

Functionality to explore the potential impacts of changing future load shapes on the renewable portfolios has been integrated into the RPS Calculator 6.1 in an exploratory modeling effort. Load shapes from three scenarios developed under E3's California PATHWAYS analysis—the Straight Line, High BEV, and Low Carbon Gas scenarios—have been incorporated into the energy value module to examine how differences in the timing of load and renewable production may impact project selection and alter portfolio composition.[8]

Load shapes, and calculations that modify load shapes based on user selections, can be found in the 'Load_Shape' tab. More information about the source of the load shape used in the RPS Calculator can be found in Appendix B.

## Resource Shapes

Resource shapes represent the characteristic temporal patterns of energy production associated with different resource types. Resource shapes are used to calculate the amount of generation and, along with the total annual load and load shapes, the "net load" for each average month-hour. Like load shapes, resource shapes in the RPS Calculator are normalized by annual usage such that the sum of the values comprising each resource shape is 100%. Generation for each year of the analysis horizon is calculated by multiplying the annual non-renewable and risk-adjusted renewable generation under contract by the corresponding resource shape.

The renewable capacity that is under contract is derived from the information stored in the 'Active_Portfolio' tab. Resource shapes, and the calculations that use resource and load shapes to determine energy value and curtailment, can be found in the 'Energy' tab. More information about the sources of the resource shapes used in the RPS Calculator can be found in Appendix B.

## Net Load

The "net load" is used to determine the avoided cost of energy in each of the 288 periods evaluated for each year. The magnitude of the net load determines how much of the stack of conventional generators must be dispatched (see explanation under "Natural Gas Dispatch" below).

Net load in a given period is calculated by subtracting generation resources, including both renewable and conventional generators, from the total system load in each period. The amount of production from each renewable resource type used in the calculation is based on the risk-adjusted total renewable capacity under contract to CAISO LSEs in that year multiplied by the appropriate resource shape. The net

[8] Additional documentation of the PATHWAYS scenarios is available at: https://ethree.com/public_projects/energy_principals_study.php

load calculation accounts for the net contribution of all hydrological power sources serving CAISO load (including pumped storage) in the 'Generators' tab as well for the positive and negative contributions of storage resources included in the 'Storage_Inputs' tab.

The net load and energy value calculations are found in the 'Energy' tab. The net load used for energy assigning energy value can be found in the range DV58:FR345. The energy value corresponding to each net load can be found in the range FU58:HQ345.

## Overgeneration

Overgeneration is calculated based on the assumption that 15% of the gross load must be met by thermal generation.[9] Overgeneration is calculated for each period as the amount of available renewable generation that is not dispatched to serve load (i.e., curtailed) due to the minimum thermal generation constraint. For periods in which there is sufficient remaining load after accounting for the contributions of renewable, nuclear, hydrological, and storage resources to allow gas and cogeneration to serve at least 15% of gross load, no overgeneration occurs.

Overgeneration calculations are found in several locations throughout the workbook, but the original source of these calculation is the 'Energy' tab. Overgeneration is calculated for each of the 288 average month hours in the 'Energy' tab in the range JK58:JK345. The "Renewables" column in the range JJ58:J345 represents the amount of renewables that are dispatched and is equal to the load net of nuclear, hydrological, storage and gas resources. The values in the range IT58:JD345 represents the amount of renewables that are available. It is also possible to calculate overgeneration as the difference between the net load in DV48:FR345 and the gas generation in JG58:JG345 (ensuring that the column in the former range corresponds to the snapshot year specified in cell JK56).

A summary of overgeneration by year is found in the range FU379:HQ379 of the 'Energy' tab. This value is equal to the sum of the product of overgeneration in each average month hour for that year and the number of days in each month. These values are reproduced in the 'Net_Short' tab on row 15. They are also used to calculate the percentage of the RPS compliance obligation that overgeneration comprises in row 53 of the the 'Net_Short' tab and I11:AA11 of the 'Dashboard.'

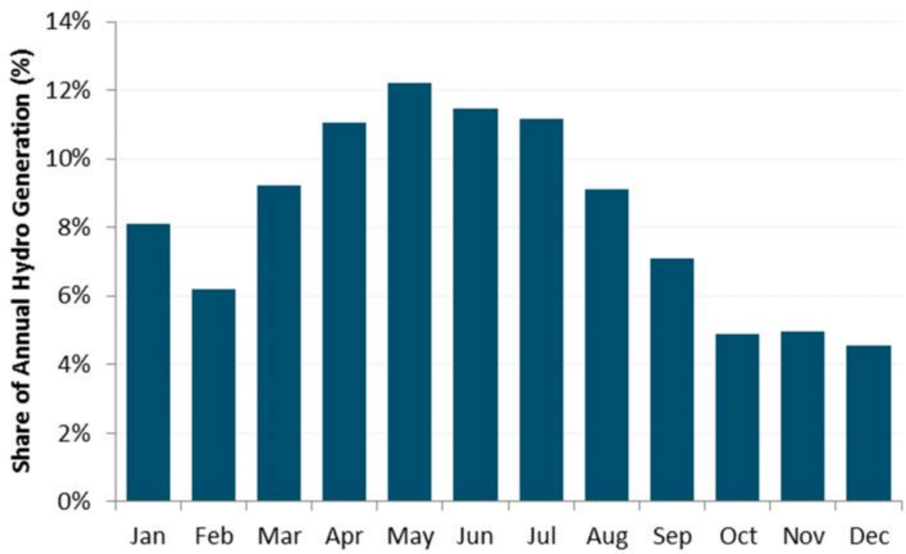
## Hydroelectric Dispatch

The dispatch of hydroelectric resources is constrained not only by the capacity of generators and the underlying hydrologic conditions but by a variety of non-power related factors as well. In order to capture both the constraints on the flexibility of the hydroelectric fleet as well as its positive correlation with net load conditions, hydro generation is modeled in the RPS Calculator using relationships derived from historical hourly operations. Within the context of the 288-period model used by the RPS Calculator, an annual energy budget is first distributed among the twelve months and then within each month among the 24 average hours using the process described below.

[9] By default, the minimum is set to 15%, cogeneration's contribution is included, and nuclear's contribution is excluded. These options can be changed in cells E6:E8 of the 'Energy' tab. Because cogeneration is never sufficient to serve 15% of the net load on its own, the default minimum is functionally a floor on gas generation. See the section "Natural Gas Dispatch" for more information.

1. **Distribute annual energy budget among the twelve months.** For each hydro generator located in CAISO or contracted to CAISO LSEs, annual energy output under average hydroelectric conditions is specified on the 'Generators' tab based on 2003 hydrologic conditions. The aggregate annual budget is distributed among the twelve months of the year using a set of allocators that sum to 100% on the 'Hydro_Param' tab. The allocators used in the model are shown in Figure 9.

**Figure 9. Distribution of annual hydro energy budget to months.**




2. **Determine upper and lower bounds on hydro output for each month based on capacity factor.** The bounds on hourly hydro operations are derived from historical analysis of the operations of the CAISO hydroelectric fleet[10] and Hoover Dam[11] over the period April 2010 through December 2011. The operating envelope shown in Figure 10 links the average capacity factor for each day to the minimum and maximum output of the aggregate hydroelectric fleet, which is used to limit the assumed range across which hydro can be dispatched in each month.

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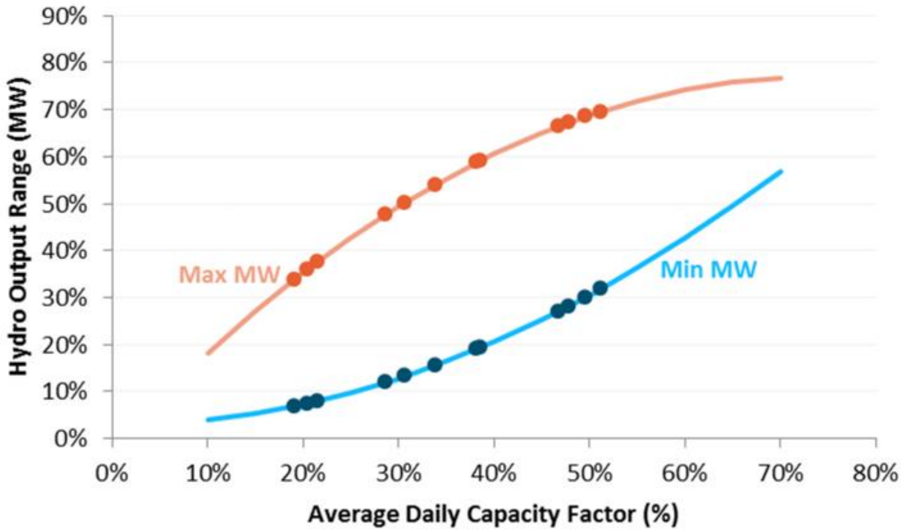
[10] Hourly data for CAISO hydroelectric generation gathered from CAISO Daily Renewables Watch: http://www.caiso.com/green/renewableswatch.html

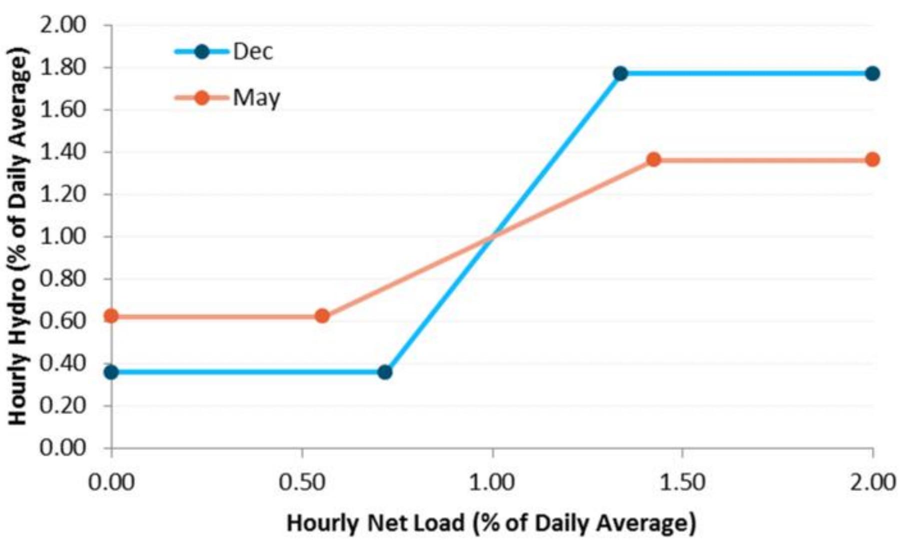
[11] Hourly data for generation from Hoover Dam for 2010 and 2011 is available from WECC: https://www.wecc.biz/TransmissionExpansionPlanning/Pages/Datasets.aspx

**Figure 10. Upper and lower bounds on hydroelectric output as a function of monthly capacity factor.**




3. **Distribute monthly hydro budget to hours of the day based on hourly net load.** The hydroelectric energy allocated to each day is distributed among the hours of the day using a linear model (bounded by the minimum and maximum levels of output established in Step 2). The linear model, also derived from observed operations between April 2010 and December 2011, varies with the capacity factor of the hydro fleet: in periods with lower hydro budgets, the output of the hydro fleet has been observed to be more responsive to net load signals than in periods with higher budgets. This effect is captured through the creation of a separate linear model for each month of the year; examples for May (high hydro) and December (low hydro) are shown in Figure 11.

**Figure 11. Example relationships between net load and hydroelectric output (December & May).**

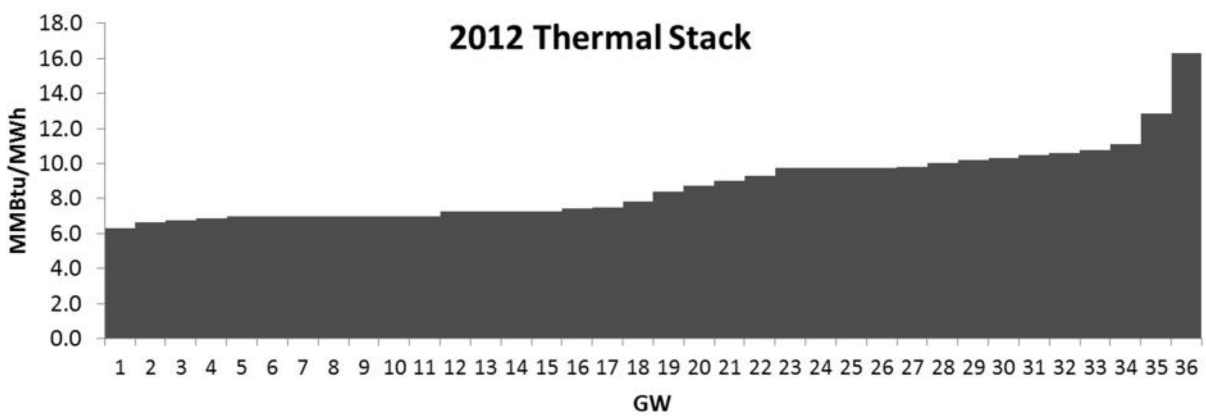


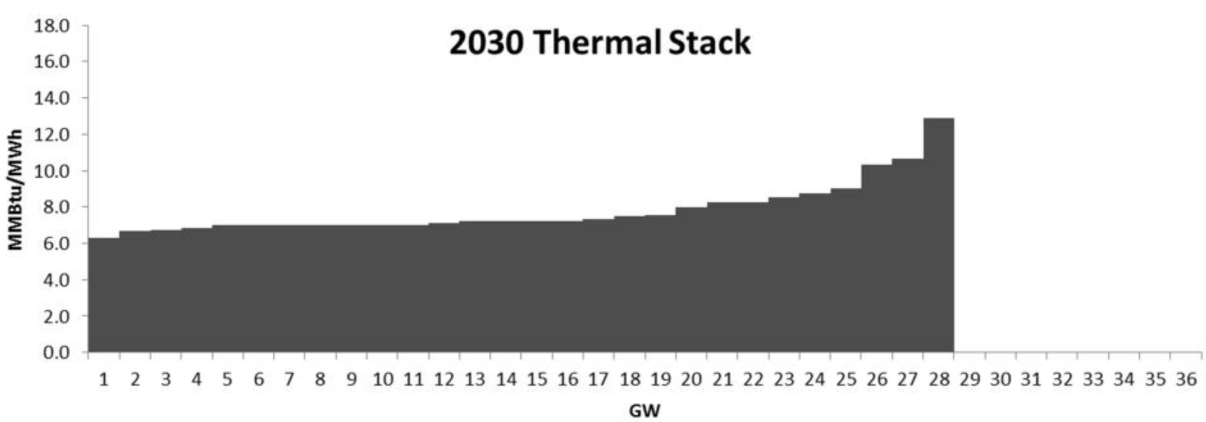
## Natural Gas Dispatch

Residual loads in each of the 288 periods that are not served by nuclear, cogeneration, hydro, or renewable generation are assumed to be met by California's gas generation fleet, which is modeled using a supply curve based on the short-run marginal cost of generation (the sum of fuel costs and variable O&M). In each year, the "stack" of gas resources available to serve load is determined based on the composition of the generators that make up the fleet in that year, accounting for expected retirements and planned additions. Over time, thus, the stack adjusts with the changing composition of California's gas fleet, as shown in Figure 12.

The RPS Calculator does constrain the output of the thermal fleet to a minimum of 15% of gross load in each hour. This constraint is derived through analysis of the historical operations of the thermal fleet as published in the CAISO's Daily Renewables Watch between April 2010 and March 2013.[12] As the Calculator's stack model does not consider the need for flexibility reserves, contingency reserves, or inertia explicitly, this constraint is intended to serve as a proxy for the impacts of such factors on the dispatch of the California fleet. The 15% constraint can be adjusted on the 'Energy' tab.

**Figure 12. Example thermal stacks for 2012 and 2030.**




[12] In the RPS Calculator, cogeneration is assumed to contribute to meeting the minimum thermal generation requirement.

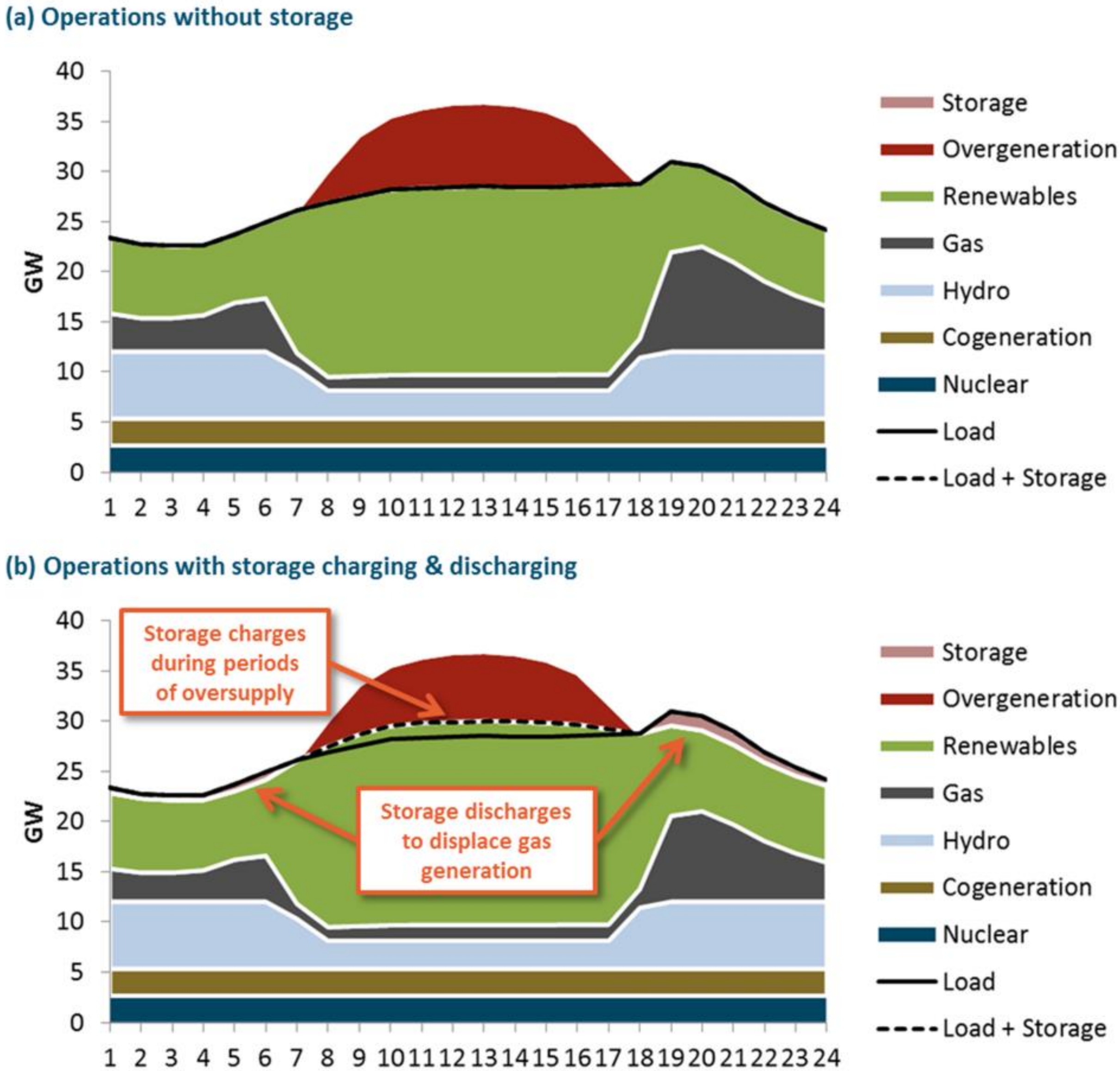
The stack model serves as the foundation for the determination of both the marginal energy value and the marginal curtailment for prospective renewable generators. Marginal energy value is determined by the marginal cost of gas generation in each of the 288 periods; combining the profile of the marginal cost with the output profiles of prospective renewable resources provides an estimate of the energy value across the year. Similarly, marginal curtailment is estimated by summing the output of each prospective resource during periods when the minimum generation constraint is binding (implying curtailment).

## Storage Dispatch

An adjustment to the dispatch of the California fleet to account for the impact of authorized incremental storage procurement is made using a simple heuristic for storage operations; this adjustment flows through to both the marginal energy value and marginal curtailment calculations for new renewable resources. As shown in Figure 13, the RPS Calculator assumes storage resources charge during periods of oversupply and discharge at other times to reduce the output of gas generation, subject to constraints on the energy and capacity limits of the storage devices assumed. Input assumptions for the characteristics of incremental storage resources is shown on the 'Storage_Inputs' tab.[13]

[13] Current assumptions regarding the deployment of incremental storage resources is based on assumptions developed in LTPP.

**Figure 13. Illustrative impact of storage on system dispatch for an April day with oversupply.**




## Transmission Allocation

The RPS Calculator allocates scarce transmission supply to renewable resources to deliver energy to load. In prior versions of the RPS Calculator (v.1.0 – v.6.0), all new renewable resources were assumed to have full capacity deliverability status (FCDS). Under this framework, each "Transmission Area"[14] is associated with a specific quantity of capacity that is currently available for interconnecting fully deliverable resources, as well as the cost and characteristics of potential transmission upgrades. Existing transmission capacity is first allocated to IOU contracts, and then to the most favorably ranked generic

[14] Transmission Areas, which may include one or more SuperCREZs, represent areas within which resources developed with FCDS are expected to have relatively similar impacts on the transmission system and the need for system upgrades.

projects. The remaining generic projects needed to fill the RNS are bundled together with minor and major upgrades, and the least-cost combination of projects (and transmission upgrades, if necessary) are selected for the portfolio.

RPS Calculator v.6.1 includes additional functionality that allows the model to select resources with energy only (EO) deliverability status, subject to the limitations of the existing transmission network. The specific limitations vary by region throughout the state. These limitations are rules of thumb intended to represent the amount of new renewable generation that could be installed without incurring major congestion. The regions to which EO Limitations apply are called "Energy Only Zones".[16]

For resources that are treated as energy only, no transmission costs are applied, but the potential capacity value that a resource could provide is also excluded from the NMV calculation due to the lack of deliverability.

## Deliverability Options

The RPS Calculator allows the user to choose from among three options for deliverability in designing a portfolio: (1) FCDS Only; (2) FCDS & EO; and (3) FCDS & EO (No New Transmission). The first of these options represents the same method for transmission allocation that has been used by the RPS Calculator historically, whereas the latter two options are functionality new to v.6.1. The specific constraints imposed on resource selection for each of these options is summarized in Table 5; a short description of the logic used in each of the allocation methods follows.

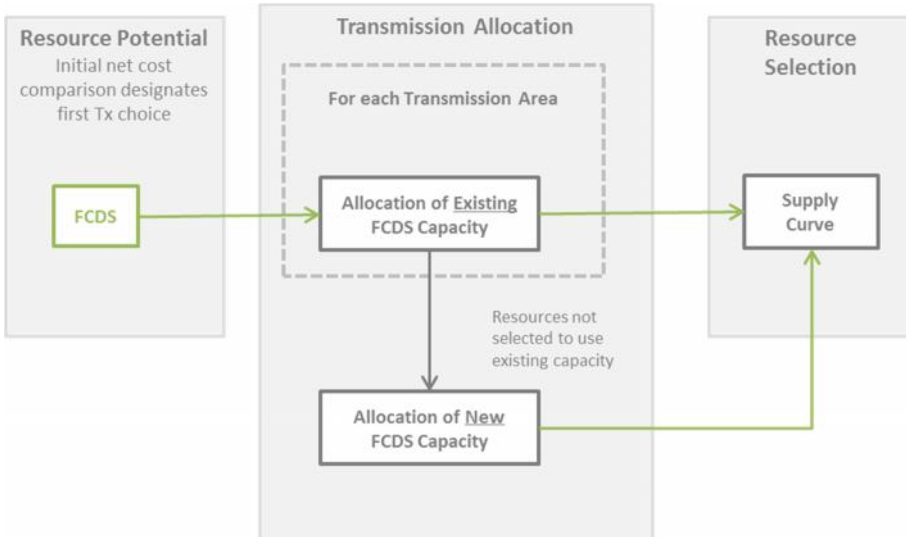
**Table 5. Constraints imposed on resource selection for each Deliverability Option.**

| RPS Calculator can select… | FCDS Only | FCDS & EO | FCDS & EO (No New Tx) |
|---|---|---|---|
| …FCDS resources on existing transmission? | **Yes** | **Yes** | **Yes** |
| …EO resources on existing transmission? | *No* | **Yes** | **Yes** |
| …FCDS resources on new transmission? | **Yes** | **Yes** | *No* |

The first transmission allocation option, 'FCDS Only', uses the same logic as earlier versions of the RPS Calculator. The generic resources with the lowest net cost in each Transmission Area are allocated available existing FCDS capacity, and any additional resources require new FCDS capacity and are attributed the costs associated with it. The supply curve includes FCDS resources on existing transmission and on new transmission, and those with the least net cost (including transmission) are selected. Figure 14 below shows how transmission is allocated when FCDS status is assumed for all new resources.

[16] Energy Only Zones, which may comprise one or more Transmission Areas, are the geographic unit to which constraints on the penetration of energy only resources apply. In some cases, an Energy Only Zone may be identical to a Transmission Area and/or CREZ (e.g. Solano is an Energy Only Zone, Transmission Area, and a SuperCREZ), whereas in other cases, an Energy Only Zone may span multiple Transmission Areas (e.g. the Northern California Energy Only Zone includes the Lassen North, Round Mountain, and Sacramento River Transmission Areas). The complete mapping between the various geographies used in the Calculator is shown on the 'Tx_Mapping' tab.

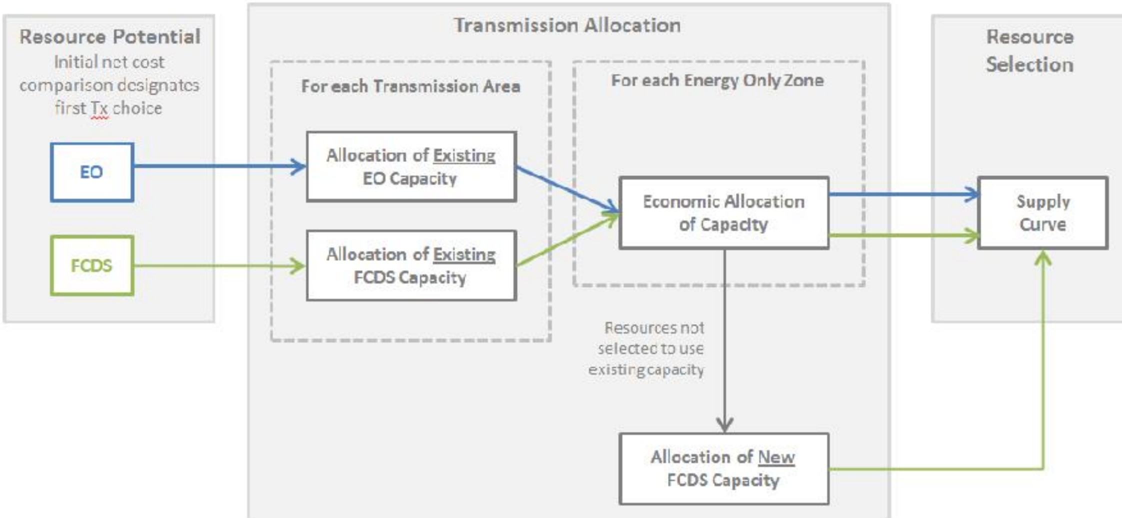
**Figure 14. "FCDS Only" transmission allocation**




The second transmission allocation option, 'FCDS & EO', allows both fully deliverable and energy only resources. First, an initial net cost screen designates each resource as "EO" or "FCDS". Resources are initially designated as EO or FCDS based on the comparative costs of any transmission upgrades needed to attain full deliverability and the capacity value that a resource provides. If the cost of the transmission upgrade exceeds the capacity value, the resource is designated as EO. Conversely, if the capacity value is greater than the cost of the transmission upgrades, the resource is designated as FCDS.

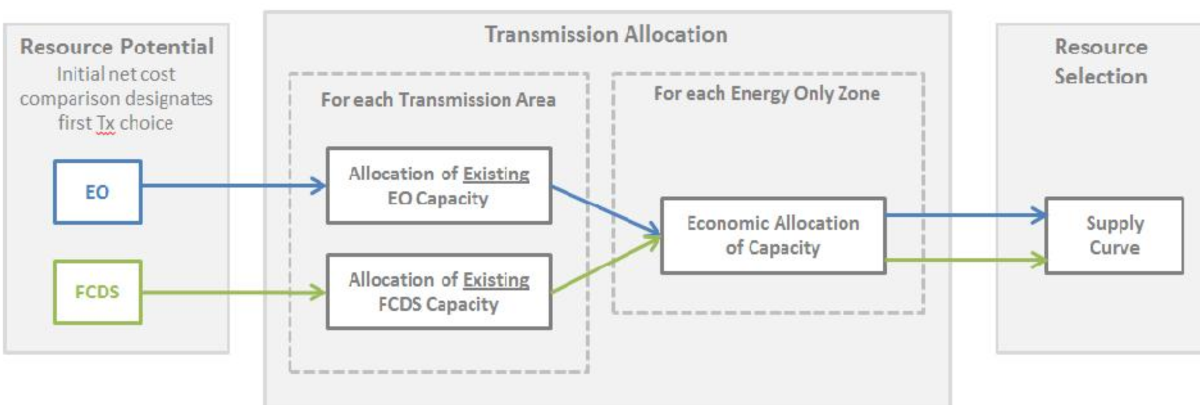
Next, existing EO and FCDS capacity within a transmission area is assigned to the best resources. These resources are then further screened within the larger energy only zone, where the best resources within the remaining existing capacity are added to the supply curve. Finally, any resources not selected to use existing transmission capacity are allocated new FCDS capacity and the associated costs. The resulting supply curve includes resources of all three types: FCDS resources on existing transmission, FCDS resources on new transmission, and EO resources on existing transmission. Figure 15**Error! Not a valid bookmark self-reference.** illustrates the allocation process when both the FCDS and EO resources are allowed.

**Figure 15. "FCDS and EO" transmission allocation**




The final option for deliverability in the RPS Calculator, 'FCDS & EO (No New Transmission)', allows both fully deliverable and energy only resources, but prohibits new deliverability network upgrades within the CAISO. In this respect, the logic utilized in this allocation of transmission capacity is very similar to the 'FCDS & EO' option, with the exception that resources that do not "fit" on the existing transmission system are excluded from the final supply curve. Figure 16 illustrates the logical sequence for the 'FCDS & EO (No New Transmission)' option.

**Figure 16. "FCDS and EO (No New Tx)" transmission allocation**




## Out-of-State Resources

The treatment of out-of-state resources varies depending on whether those resources are considered as fully deliverable or energy only. Each potential out-of-state resource is linked to a specific "gateway" CREZ, which represents the most likely point of injection to the California system. When out-of-state resources are treated as fully deliverable, they require both new transmission to deliver the energy to the California border as well as an in-state transmission upgrade from the corresponding "gateway

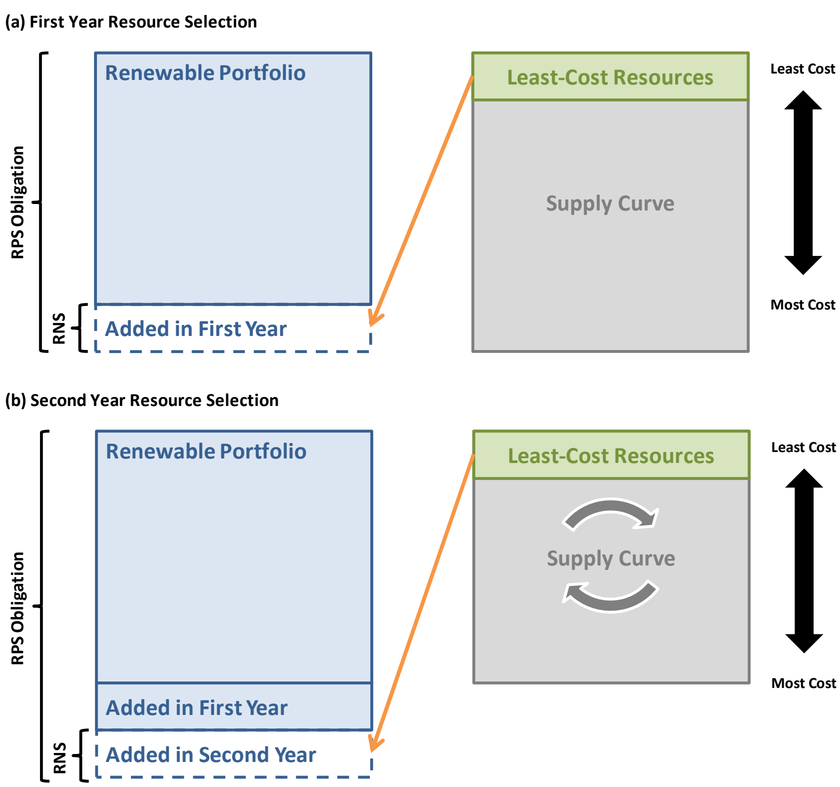
CREZ" to which the energy is delivered. When out-of-state resources are treated as energy-only, they require only the new out-of-state transmission to reach the California border, but their capacity is counted against the limits for energy-only resources imposed on the corresponding Energy Only Zone. Whether out-of-state resources are treated as fully deliverable or energy only varies depending on the Deliverability Option selected by the user:

- **FCDS Only:** All out-of-state resources are considered only as FCDS.
- **FCDS & EO:** All out-of-state resources are considered as the lower cost option between FCDS or EO.
- **FCDS & EO (No New Transmission):** All out-of-state resources are considered only as EO.

## Resource Selection

In each year of the analysis horizon, the RPS Calculator selects generic renewable projects with the lowest net cost to fill the renewable net short, subject to limitations on resource potential and transmission availability. As the CAISO-wide renewable portfolio changes, the marginal benefits and costs of each generic project also change, which leads to the order of resources in the supply curve to adjust as each project's net cost changes. This iterative resource selection process is depicted in Figure 17, which illustrates the adjustment of the supply curves used in the first and second year of the RPS Calculator's selection process.

**Figure 17. Illustrative diagram of iterative resource selection process**



# Appendix B. Development of Model Inputs

## Load Forecast

The RPS Calculator incorporates assumptions from the load forecast from the CEC's Integrated Energy Policy Report, which includes forecasts of the retail sales, net energy for load, and peak demand in the CAISO; this data is used for comparable purposes in the CPUC's LTPP. The CEC's IEPR is also used as the source for the forecast of behind-the-meter PV adoption through time.

The load forecasts incorporated from the CEC's IEPR are shown on the 'Load_Forecast' tab in the model. Because the RPS Calculator tracks the procurement and compliance position of the each of the IOUs' bundled customers separately, load forecasts are incorporated with this level of granularity. Other loads within the CAISO but not served by the IOUs' bundled portfolios are grouped together into the category of 'Other CAISO.' The LSEs included within the 'Other CAISO' category are shown in Table 6.

**Table 6. LSEs included in the 'Other CAISO' aggregation.**

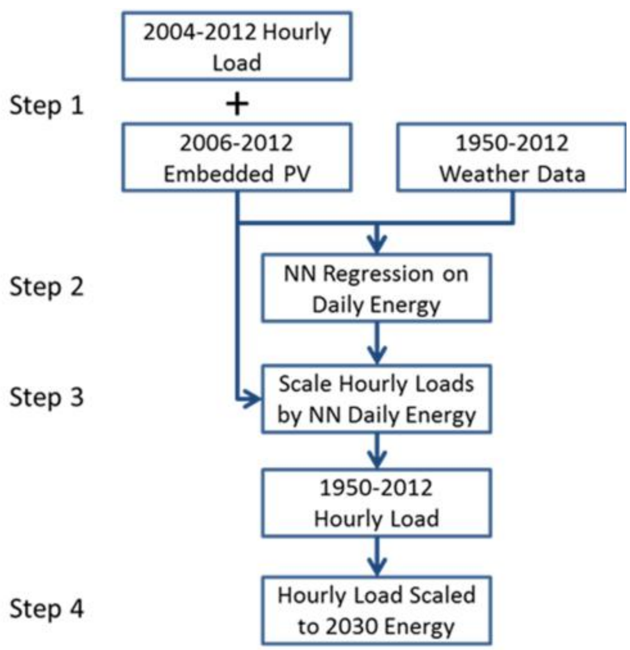
| Planning Area | 'Other CAISO' LSEs |
|---|---|
| PG&E | • Calaveras Public Power Agency<br>• City of Alameda<br>• City of Biggs<br>• City of Gridley<br>• City of Healdsburg<br>• City of Hercules<br>• City of Lodi<br>• City of Lompoc<br>• City of Palo Alto<br>• City of San Francisco<br>• City of Ukiah<br>• Island Energy/Pittsburg<br>• Lassen Municipal Utility District<br>• Pacific Gas and Electric Company (Direct Access)<br>• Plumas-Sierra Rural Electric Cooperation<br>• Port of Oakland<br>• Port of Stockton<br>• Silicon Valley Power<br>• Tuolumne County Public Power Agency |
| SCE | • Anza Electric Cooperative, Inc.<br>• Azusa Light & Water<br>• Bear Valley Electric Service<br>• City of Anaheim<br>• City of Banning<br>• City of Colton<br>• City of Corona<br>• City of Rancho Cucamonga |

| | |
|---|---|
| | • City of Riverside<br>• City of Vernon<br>• Metropolitan Water District<br>• Moreno Valley Utilities<br>• Southern California Edison Company (Direct Access)<br>• Valley Electric Association, Inc.<br>• Victorville Municipal |
| SDG&E | • San Diego Gas and Electric Company (Direct Access) |

# Load Shapes

Load shapes were generated using a neural network-based approach to predict daily CAISO load energy under historical weather conditions. The approach is shown in **Error! Reference source not found.** and each step (1-4) is described in more detail below.

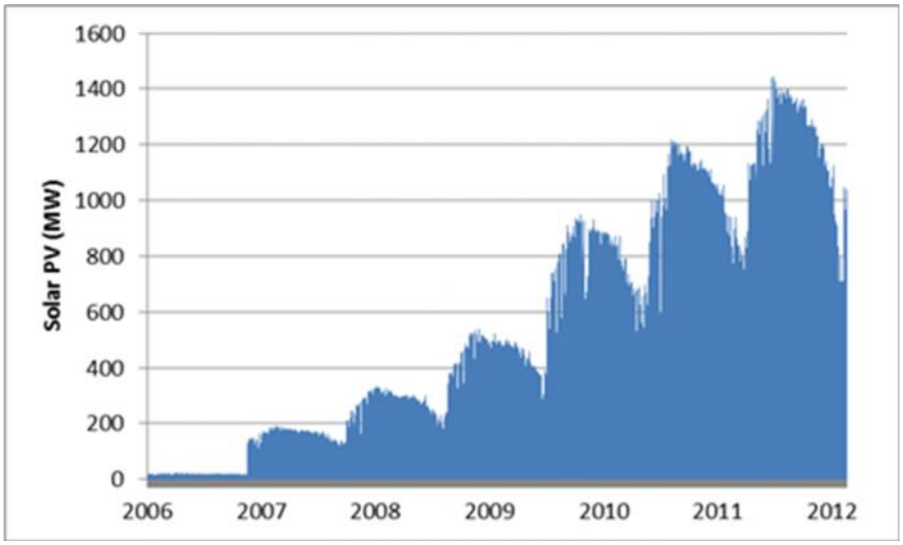
**Figure 18: Methodology for creating 2030 load profiles**




***Step 1:*** Create an hourly aggregate load profile using CAISO hourly loads and simulating behind-the-meter PV for 2006-2012. The behind the meter PV, shown in

Figure 19, is grossed up for T&D losses.

**Figure 19: Embedded Solar PV 2006-2012 and Avoided T&D Losses**



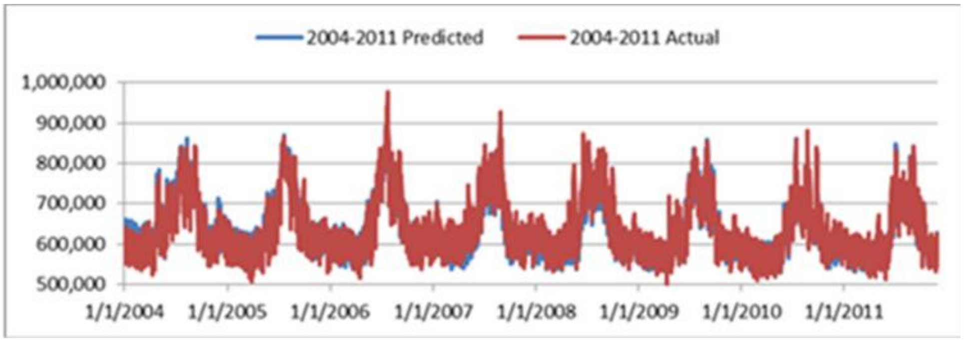

*Step 2:* **Develop an artificial neural network using the following explanatory variables, shown in Table 7, to predict daily CAISO energy: temperature (daily high/low at eight California locations) as well as lag/lead temperature (D-1,D-2,D+1) due to their impacts on heating and cooling load; a solar azimuth variable; a Boolean variable for the first half of the year (Day=1..183); a Boolean workday indicator; and a day number index that is utilized in to capture any additional trends in the underlying load data not explained by other variables (economic factors, population growth, load types, etc.).**

Figure 20 shows the model fit.

**Table 7: Neural Network Variables**

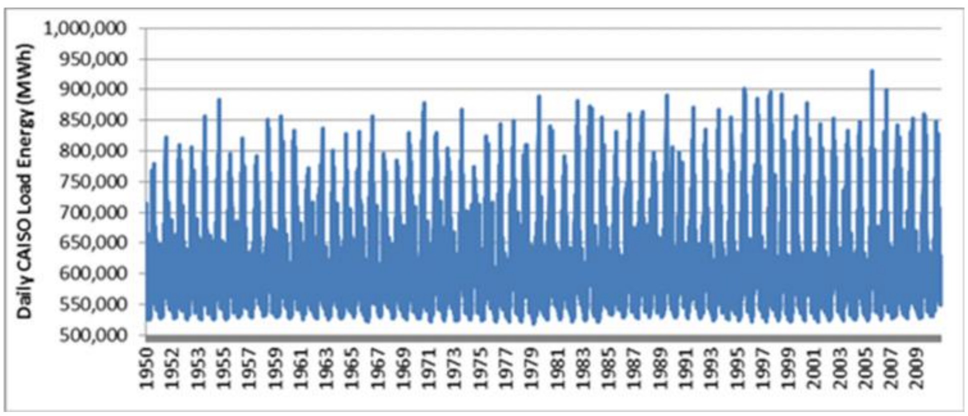
| Explanatory Variable |
|---|
| Daily High Temperature: Burbank, Fresno, Ukiah, Long Beach, Riverside, Sacramento, San Francisco, San Jose |
| Daily Low Temperature: Burbank, Fresno, Ukiah, Long Beach, Riverside, Sacramento, San Francisco, San Jose |
| Solar Azimuth |
| First Half of Year {0,1} |
| Workday {0,1} |
| Day Number Index (ex. Jan 1, 2004=1) |

**Figure 20: Predicted vs. actual CAISO daily energy for 2004-2011**




The neural network model is used to predict daily energy for 2012 demographic and economic conditions under historic weather conditions. The result of the regression is shown in Figure 21 for CAISO load only.

**Figure 21: 1950-2011 CAISO daily energy**




***Step 3:*** Use a daily energy matching function to produce hourly load data back to 1950. For all years without hourly data (1950-2003) the chosen normalized daily shape is multiplied by daily energy to produce hourly profiles. The normalized daily shape is chosen from those years where hourly data is available (2004-2012) based on the closest match of total daily energy. Matched days are within 15 calendar days of each other so that seasonally specific diurnal trends are preserved. In addition, weekdays and weekends are matched separately.

***Step 4:*** The resulting 63 years of hourly load profiles are scaled to the expected 2022 energy and median peak load. Behind-the-meter PV is introduced as separate profiles.

The hourly load profiles were averaged and normalized to produce the array found in E58:E345 of the 'Energy' tab and F17:F304 of the 'Load Shapes' tab.

## Resource Shapes

The resource shapes used in the RPS Calculator are derived from a variety of different sources.

- **Nuclear:** Output from nuclear facilities includes the production from Diablo Canyon nuclear facility[17] (2,300 MW) as well as the share of the Palo Verde facility contracted to LSEs located within the CAISO (709 MW). Nuclear plants are assumed to run at a 90% capacity factor with a flat baseload profile throughout the year.
- **Cogeneration:** The fleet of non-dispatchable cogeneration plants located within CAISO is assumed to operate at a 90% capacity factor relative to August NQC values; a flat baseload profile is applied to these resources as well.
- **Baseload:** A baseload profile (flat throughout the year) is applied to resources whose output is not variable and intermittent (e.g. biomass & geothermal).
- **CSP (Storage & No Storage):** Profile simulated by E3 using data gathered from NREL's Solar Prospector from 1998-2005 and the System Advisor Model (SAM) produced by NREL.
- **Solar PV (Distributed):** Profile simulated by E3 using hourly irradiance and weather data gathered from NREL's Solar Prospector for the years 1998-2005 and the default technology assumptions in NREL's PVWatts Calculator.
- **Solar PV (Fixed Tilt & Tracking):** Profiles developed by Black & Veatch to represent solar performance over the course of a typical meteorological year (see Resource Potential section for more details).
- **Wind (Inland & Coastal):** Profiles based on NREL's Western Wind Integration (WWI) dataset using an average of data for locations nearest to known existing wind resource locations and potential locations identified in RETI. (The WWI data was modeled by 3TIER using the Weather Research & Forecasting (WRF) model to downscale the NCEP/NCAR reanalysis data. The data may be accessed at http://wind.nrel.gov/Web_nrel/. The data was produced for phase 1 of the western wind and solar integration study 2009-2010.
http://www.nrel.gov/electricity/transmission/western-wind-1.html).
- **Wind (Northwest, Rocky Mountain & Southwest):** Profiles based on Black & Veatch's Western Renewable Energy Zones (WREZ) modeling efforts (see Resource Potential section for more details).

## Resource Costs & Potential

Black & Veatch developed cost and performance information from internal sources, market data, and other literature sources. When possible, previously-vetted information from other Black & Veatch stakeholder projects was used:

- Renewable Energy Transmission Initiative (RETI, 2008-2010)[18]
- Western Renewable Energy Zones (WREZ, 2009, 2012-2013)[19]

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[17] The retirement date assumption for the Diablo Canyon Power Plant, and other non-RPS eligible generators, can be adjusted in the 'Generators' worksheet under column M.
[18] http://www.energy.ca.gov/reti/documents/

- SB1122 Biomass Feed-in Tariff (2013)[20]
- NREL Renewable Electricity Futures (2010)[21]

Since both RETI and WREZ were extensive stakeholder-driven processes, the approaches adopted in those efforts formed the basis of the assessments for each technology. The information presented in this section is a high-level overview of the approach. A considerable amount of additional detail on the methodology for developing cost and resource potential estimates is available in the reports referenced above. Due to market changes since the previous work was completed, Black & Veatch modified the data for use in the RPS Calculator, as highlighted in each technology section below.

## Resource Costs

### *Capital and Operating Costs*

The capital and operating costs that are used in the RPS Calculator are comprehensive and include all costs required for complete development, construction, and operation of each project. Key characteristics of capital and operating cost data in the RPS Calculator include:

- Costs are "all-in" installed costs and include engineering, procurement, and construction (EPC) plus owner's costs (soft costs)
- Costs include costs through the interconnection to the T&D system
- Future cost forecast curves were developed for all technologies to account for cost declines over time
- O&M cost estimates include all other annual costs, including land lease, and insurance
- Property tax is calculated separately and explicitly using an assumption of 1% of book value assuming straight line depreciation

#### Changes in Version 6.1

The approach outlined above formed the basis for the cost estimates for most technologies. Variations and changes between v.6.0 and v.6.1 include the following:

- Solar PV: Capital costs are roughly 25 percent lower than v.6.0, reflecting continued cost declines in the industry. Adjustment to out-of-state capital costs applied to reflect regional variations in costs.
- Wind: Current wind turbine and plant construction prices are down roughly 7 percent. Out-of-state capital costs reflect regional cost variation and local terrain impacts.
- Geothermal: An update was made to the capital costs from three major sources:
    - NREL Salton Sea analysis (to be released)
    - 2014 WECC/E3 Survey[22]

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19 http://www.westgov.org/rtep/219-western-renewable-energy-zones
20 http://www.cpuc.ca.gov/PUC/energy/Renewables/hot/SB_1122_Bioenergy_Feed-in_Tariff.htm
21 http://www.nrel.gov/analysis/re_futures/

- 2014 CEC IEPR[23]

The results of this survey found that the average capital cost of projects was 6,774 $/kW, a 31 percent increase over 2013 capital cost estimates in v.6.0 of the Calculator. This increase was applied to all projects in the v.6.1 geothermal database.

- Biomass: Capital costs were modified for inflation and an interconnection cost adder of $200/kW was applied.
- Solar Thermal: General inflation costs were applied to past capital cost estimates.

#### References

General sources of data used during the cost analysis include the following:

- Black & Veatch estimates developed through detailed design & construction projects. Bottoms-up cost estimates were performed using data in this fashion for solar PV, solar thermal, wind, and biomass;
- Financial due diligence from independent engineering assessments;
- Bid reviews for developers, utilities, and others; and
- Market modeling and assessments, including nodal market modeling, forecasts, integrated resource planning, locational marginal pricing.

### *Financing Inputs*

The RPS Calculator uses a simple pro-forma cash flow model that simulates a power purchase agreement between a credit-worthy offtaker (i.e. California utility) and a third-party developer. The financial inputs to this model include:

- After-tax weighted average cost of capital (WACC);
- Financing lifetime (or PPA term);
- Cost of debt;
- Debt tenor; and
- Minimum debt service coverage ratio (DSCR).

The pro-forma model uses these inputs to determine the capital structure for each technology that maximizes an individual project's leverage while meeting the minimum DSCR constraint; thus, the shares of debt and equity and the project's equity return are results of, rather than inputs to, the financial model.

The input assumptions used in the pro-forma model are selected by E3 based on a combination of industry expertise and a review of literature regarding the renewable finance industry. Sources reviewed by E3 in the development of these assumptions are noted below.

#### References


- E3, 2014. "Capital Cost Review of Power Generation Technologies: Recommendations for WECC's 10- and 20-Year Studies." Available at: https://www.wecc.biz/Reliability/2014_TEPPC_Generation_CapCost_Report_E3.pdf.
- Lawrence Berkeley National Lab (LBNL), 2014. "An Analysis of the Costs, Benefits, and Implications of Different Approaches to Capturing the Value of Renewable Energy Tax Incentives." Available at: http://eetd.lbl.gov/sites/all/files/lbnl-6610e_0.pdf.
- National Renewable Energy Laboratory (NREL), 2011. "P50? P90? Exceedance Probabilities Demystified." Available at: https://financere.nrel.gov/finance/content/p50-p90-exceedance-probabilities-demystified.
- NREL, 2012. "Renewable Energy Finance Tracking Initiative (REFTI) Solar Trend Analysis." Available at: http://www.nrel.gov/docs/fy12osti/53531.pdf.


### *Tax Benefits*

The costs of renewable generation are also influence by federal tax policies and incentives. In its calculation of future renewable costs, the RPS Calculator accounts for three federal tax policies with such impacts:

- The Production Tax Credit (PTC);
- The Investment Tax Credit (ITC); and
- The Modified Accelerated Cost Recovery System (MACRS) depreciation benefits.

Each of these policies is modeled for applicable technologies only through the time horizon through which it is currently enacted in federal tax law; for projects developed thereafter, the benefits are no longer assumed to apply.[24]

### *Future Capital Cost Declines*

While forecasts for future costs of energy technologies are almost never correct, they are useful because they provide a best guess and can help identify trends. Future cost curves in v.6.1 of the Calculator are based on the National Renewable Energy Lab (NREL) Renewable Electricity Futures study supported by Black & Veatch. This study entailed a stakeholder process that reviewed various technologies, and provided future performance and cost projections.

Since this study was completed, results were updated to reflect changes in market from 2010 to 2013 (cost declines projected to occur, did occur) and from 2013 to 2015 based on a range of different media sources and Black & Veatch cost databases. In addition, in order to perform a sensitivity analysis on aggressive forecasts in the decline of solar PV pricing, an additional solar PV cost trajectory was developed by Black & Veatch that reflects the goals of the DOE SunShot initiative. A summary of the expected future cost declines (in real terms) for selected technologies are shown in Table 8.

[24] The current status and applicability of tax incentives to the various renewable technologies is based on the Database of State Incentives for Renewables & Efficiency (DSIRE), available at: http://programs.dsireusa.org/system/program.

**Table 8. Anticipated future capital cost reductions.**

| Year | Solar PV – Fixed | Solar PV – Tracking | Solar Thermal | Wind |
|---|---|---|---|---|
| 2015 | 100% | 100% | 98% | 100% |
| 2020 | 91% | 92% | 95% | 99% |
| 2025 | 86% | 88% | 90% | 98% |
| 2030 | 82% | 85% | 86% | 97% |

For biomass, biogas, and geothermal, it is assumed that the technology is relative mature and that their costs will not improve over time.

### References

- NREL Renewable Electricity Futures (REF): http://www.nrel.gov/analysis/re_futures/
- DOE Sunshot Goals: http://energy.gov/eere/sunshot/photovoltaics

## Resource Potential

### *Zone Identification Approach*

From 2008-2010, Black & Veatch worked with stakeholders to identify Competitive Renewable Energy Zones (CREZ) as part of RETI. These zones were subsequently used in different processes by various stakeholders. In 2013-2015, Black & Veatch reassessed renewable resources to address significant improvements in renewable technology, largely due to much more widespread solar PV potential and new wind resources identified in northern California. This represents a major change from the renewable resource assessment performed in RETI. Most of these resources are outside previous CREZ boundaries.

A set of principals were established for updating zone boundaries. New zones are based on:

- "Legacy" 2010 CREZ to the extent possible
- Locations of ~150 projects which have been "tagged" to zones in the CPUC's 2012 RPS calculator
- Expanded resource assessment (tried to not split newly identified projects into two zones)
- Transmission topology
- Geographic constraints
- County boundaries

Previous CREZs identified the best resources for large scale transmission development considering technical, economic and environmental factors. This created very specific boundaries, sometimes capturing specific projects and interconnection lines. Work was performed to make RETI CREZs as small as possible ("shrink-wrapped") to minimize perceived environmental footprint. Current zones are intended to capture most of the resources in California, which represents a much wider area.  In doing so, this has created comprehensive coverage of the state, with boundaries that are less meaningful when compared to what was performed in RETI.

The new SuperCREZ boundaries largely correspond with a legacy zone name or a zone in the 2012 RPS calculator. No new zones have been identified, with the exception of the Sacramento River Valley. Any resources outside the legacy RETI CREZ zones and Sacramento River Valley are summarized by county.

A very important note to remember when reviewing the areas within a Super CREZ is that they incorporate land that may be excluded for development due to land use and environmental screens. Unlike the RETI CREZ boundaries, the v.6.1 Super CREZ boundaries are not drawn with the intent to only capture land available for renewable development.

### *Land Use Exclusions*

In the identification of locations suitable for renewable resource development, Black & Veatch used a series of exclusion screens to filter out land and resources that would not be appropriate for development and should not be part of the analysis. This includes land that is environmentally or culturally sensitive, restricted for military purposes, or inappropriate for certain types of development (such as wind development near airport runways). Most of the screens were applicable to all resources, though some screens were applicable only to certain technologies; these have been addressed in each of the resource sections.

To develop the exclusion screens, Black & Veatch solicited and received input from a variety of sources. Environmental, cultural and land use screens were vetted by the RETI Environmental Working Group and provided to Black & Veatch, while military restrictions on development were provided by the military. In developing screens that impacted specific types of resources, Black & Veatch consulted with developers and stakeholders in those represented industries.

General land exclusions include the following:

- Military Lands
- Tribal Lands
- Active Mines
- Airports
- Urban and Built-up Land
- Water Bodies

In performing environmental development restrictions, focus has been to remove lands where development is prohibited or practically impossible. Stakeholder vetted public datasets were used in the analysis. For in-state restrictions, the RETI Category 1 ("Development Prohibited") set of restrictions were used. These restrictions are summarized in Table 9.

**Table 9. Land use classifications included in RETI Category 1 exclusions.**

| Land Use Type | Notes |
|---|---|
| Designated Federal Wilderness Areas | Private preserves of The Wildlands Conservancy |
| Wilderness Study Areas | Existing Conservation Mitigation banks under conservation easement approved by the state Department of Fish and Game, U.S. Fish and Wildlife Service or Army Corps of Engineers |
| National Wildlife Refuges | CA state defined wetlands |
| Units of National Park System (National Parks, National Monuments, National Recreation Areas, National Historic Sites, National Historic Parks, National Preserves) | CA State Wilderness Areas |
| Inventoried Roadless Areas on USFS national forests | CA State Parks |
| National Historic and National Scenic Trails | DFG Wildlife Areas and Ecological Reserves |
| National Wild, Scenic and Recreational Rivers | BLM National Monuments |
| BLM King Range Conservation Area, Black Rock-High Rock National Conservation Area, and Headwaters Forest Reserve | Lands precluded by development under Habitat Conservation Plans and Natural Community Conservation Plans |
| BLM National Recreation Areas | Lands specified as of May 1, 2008 in Proposed Wilderness Bills (S. 493, H.R. 3682) |

In addition, the RETI category 1 lands were combined with data from the more recent Western Electricity Coordinating Council Environmental Data Task Force. Specifically, Category 4 ("Areas Presently Precluded by Laws or Regulation") locations were removed from the analysis. Finally, lands restricted for development as a result of the Feinstein California Desert Protection Act were also excluded. The resulting exclusion areas were compared to lands excluded by the Desert Renewable Energy Conservation Plan (DRECP) in southern California and found to be consistent.

For out-of-state resources, Western Electricity Coordinating Council Environmental Data Task Force Category 4 ("Areas Presently Precluded by Laws or Regulation") locations were removed from the analysis.

While other areas may be classified as environmentally sensitive, the RPS Calculator has not screened out any other lands for environmental reasons so as not to prejudge permitting processes.

### References

- RETI Environmental Working Group: http://www.energy.ca.gov/reti/steering/workgroups/environmental/
- Western Electricity Coordinating Council Environmental Data Task Force:

  https://www.wecc.biz/TransmissionExpansionPlanning/Pages/Environmental-and-Cultural-Considerations.aspx

## *Solar PV – Utility Scale*

Black & Veatch downloaded typical global horizontal year (TGY) solar data for the entire state of California from the same dataset used in NREL's Solar Power Prospector (SPP). This dataset consists of irradiance data for a grid of 10 km by 10 km cells for a statistically typical year based on satellite data from 1998 to 2009. This dataset was generated by the State University of New York/Albany (SUNY) satellite radiation model developed by Richard Perez and Clean Power Research. The use of typical year datasets for solar energy production estimates is an industry standard approach. The general methodology used to generate a typical year dataset such as TGY is as follows:

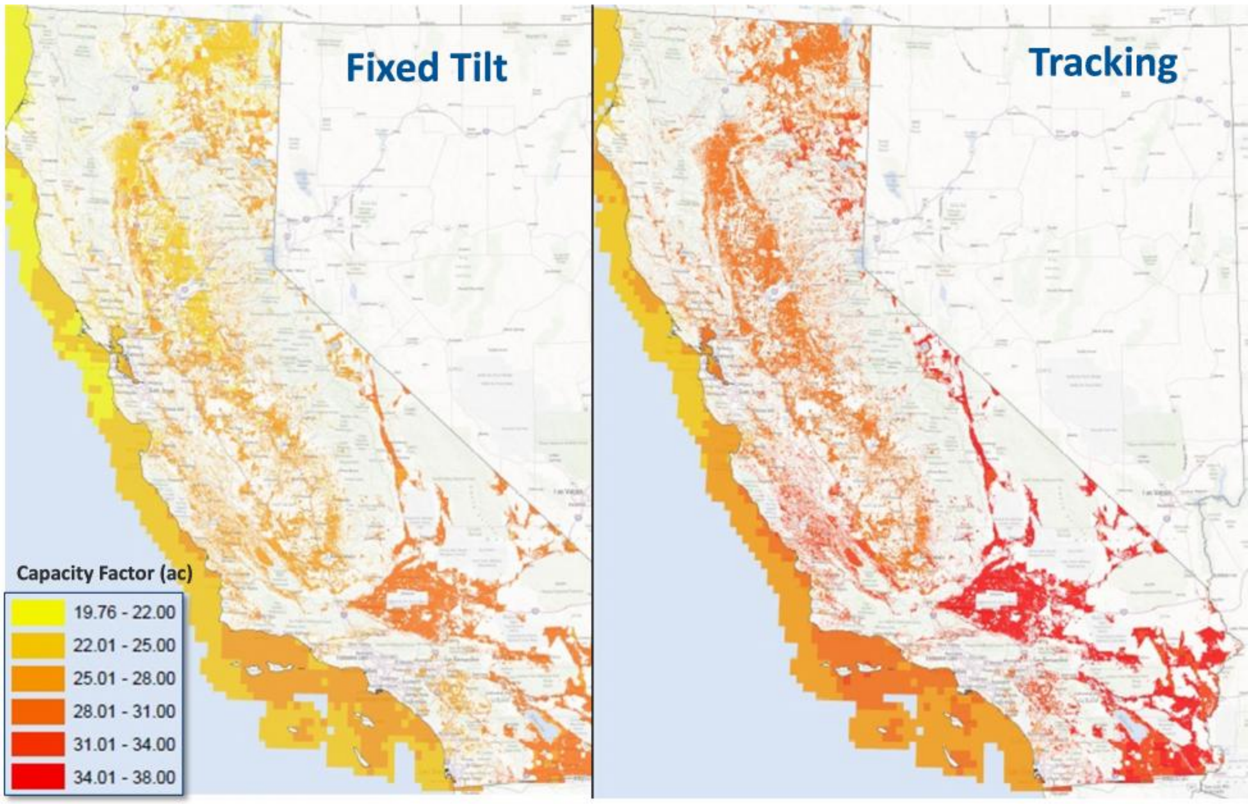
- The multi-year annual and monthly data available for a specific location is collected
- Monthly datasets over all of the available years in the data are collected and analyzed to find the most typical solar resource and weather conditions (for that month, at that location, within that database)
- Each particular year's monthly dataset is compared against the median conditions for that month. The year that has conditions which are closest to the median is selected as being the most typical and becomes the Typical Year's dataset for that month.
- This process is then repeated separately for all twelve months to construct the full-year Typical Year dataset

This method is employed to generate Typical Year datasets because it preserves the essential hour-by-hour variability in solar resource data that would otherwise be smoothed away if an averaging process were utilized instead.

The gridded irradiance data was fed into NREL's System Advisor Model (SAM) which simulates the performance of PV systems. Typical annual generation was modeled for every 10 x 10 km grid square in California for fixed, single-axis tracking, and rooftop PV systems (more than 15,000 simulations). Designs were assumed to utilize polycrystalline modules, with standard technical assumptions for inverter loading ratio (1.40 for fixed tilt and 1.30 for tracking), azimuth (south facing), tilt (latitude minus 5 degrees for fixed and 0 degrees for tracking), and losses.

After application of general and environmental screens, land that is protected by the Williamson Act and areas with slopes over five percent were removed from consideration. The land remaining represents the raw resource potential available for solar PV development. This reflects a very large amount of land throughout the state as shown in Figure 2218. To convert the acres of solar PV potential by county to a MW estimate, a conservative factor of 10 acres per MW was applied. While it is understood that many projects are able to use less land during project development, future discounts applied to estimate developable potential make accuracy of this number less critical.

**Figure 22. Identification of potential generic California solar PV resources.**




This technical potential was converted to a developable potential by using a 95 percent discount factor for purposes of the Calculator. Even with this discount, the potential for solar PV throughout California is very high, over 120 GW in the base case.

### References

- Full Dataset: http://www.ngdc.noaa.gov/docucomp/page?xml=NOAA/NESDIS/NCDC/Geoportal/iso/xml/C00845.xml&view=getDataView&header=none
- NREL Solar Power Prospector (includes map for downloading data for specific location): http://maps.nrel.gov/prospector
- Solar Irradiance Dataset User Manual: http://www1.ncdc.noaa.gov/pub/data/nsrdb-solar/documentation-2010/NSRDB_UserManual_r20120906.pdf
- Solar Irradiance Dataset Methodology: http://www.nrel.gov/docs/fy14osti/60886.pdf
- NREL SAM model: https://sam.nrel.gov/

### *Wind*

Wind turbine power output is proportional to the cube of wind speed, which makes small differences in wind speed very significant. Over the past several years there have been several wind resource assessment initiatives which have generally resulted in the production of high resolution maps showing wind speed and wind power density. This work has been undertaken by public entities such as NREL and CEC, and private companies such as AWS Truepower (AWST). Black & Veatch took two approaches to identifying and characterizing wind projects. A more detailed approach was used to identify projects in California, as more detailed source data was available, along with results from previous California studies. A broader approach was used outside of California, reflecting the larger geographic area and less detailed source data.

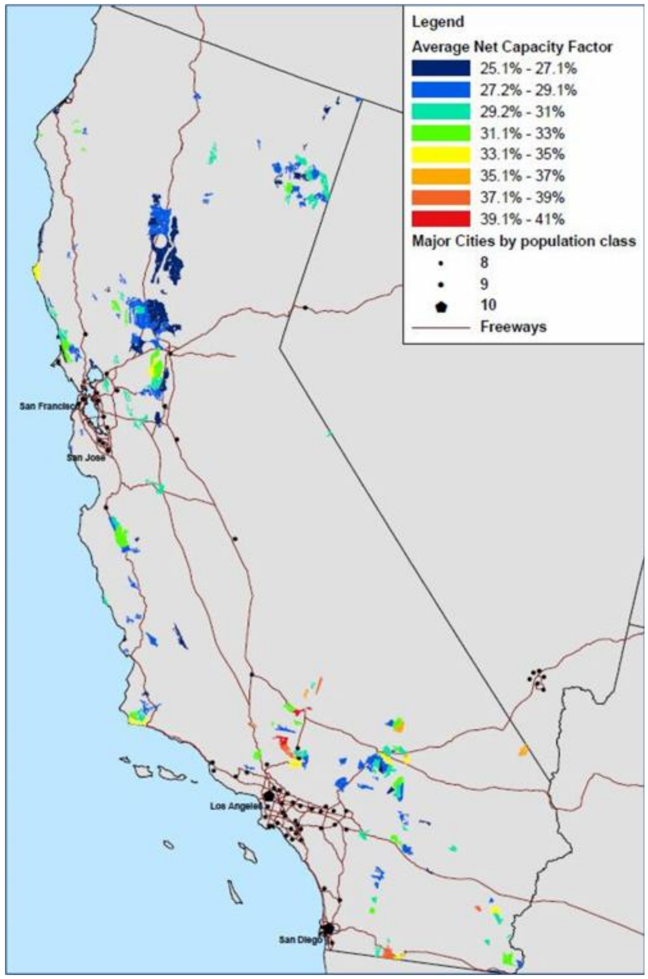
Identification for wind projects in California was based on a high resolution AWST wind speed dataset, produced as part of the Energy Commission’s Intermittency Analysis Project. The data included wind speed, wind direction, and Weibull shape and scale parameters for a 200 meter by 200 meter grid over the entire state of California in GIS format.

Information on California’s terrain, land use, and environmental designations was used to identify specific areas excluded from the development of utility scale wind energy projects. The areas that were excluded from the proxy wind development analysis included:

- Land identified as “Red” by the Department of Defense in their maps of restricted airspace.
- Areas adjacent to major airports. Major airports have significant FAA restrictions on wind development in the flight path.
- Land with greater than 20 percent slope. Slope was calculated as the median slope for each quarter section. Land with slope higher than 20 percent is considered too difficult to construct.
- Areas with annual average wind speeds of less than 5.5 meters per second.
- Existing wind projects.

After application of this approach and the screens above, Black & Veatch identified hypothetical wind project locations with specific boundaries. A map of the project locations and the corresponding potential capacity factors can be seen in Figure 2319.

**Figure 23. Potential California wind sites identified for inclusion in RPS Calculator.**




Nameplate project capacity was determined for each site by estimating how many turbines could be placed within the prospective wind class area within each site. While the final spacing of turbines is dependent on many site specific characteristics, research has shown that energy deficits due to wake effects tend to decrease with increasing wind speed. As such, Black & Veatch implemented a general wind class specific "rule of thumb" where each subsequently higher wind class area is assigned a tighter spatial distribution for turbine placement. Each area is also assigned a specific multiplier to compensate for terrain-based (flat, hilly, ridgeline) land availability issues at each site. These values for terrain and spacing are based upon industry standard practices and Black & Veatch's project experience. Besides development of utility scale resources, estimates were also made for where distributed wind projects (2-20 MW) could be sited using similar constraints that are close to existing substations.

In v.6.0, a large new wind resource in the Sacramento Valley was added; advancements in low speed wind turbines make this location now potentially attractive to development. However, to reflect uncertainty in the developable potential given the lack of current knowledge at this location, the estimated potential was discounted by 50 percent.

Capacity factor estimates were derived from the AWST wind speed data (adjusted for altitude) and representative turbine power curves. A representative turbine power curve was determined by averaging the power curves from three turbine manufacturers' models for IEC classes I, II and III. A general loss factor of 12 percent was used to calculate net capacity factor from gross capacity factor. Losses come from many sources include icing, turbine availability, grid availability, and high wind hysteresis. An in-depth analysis of losses on a per project basis was not performed.

Identification of wind potential out of state was based on the Western Renewable Energy Zones (WREZ) Generation and Transmission Model (GTM), version 3. This model was developed by Black & Veatch under contract to NREL. The output profiles for wind resources in the WREZ model were developed by AWST under a separate agreement with NREL. Black & Veatch adapted these profiles with minor modifications for the WREZ GTM model.

Updates to project performance within the WREZ zones were developed using published maps from the US Department of Energy. These maps show predicted annual average wind speed at 80 meters above ground level, as modeled by AWST. Black & Veatch used these average wind speeds, along with the assumption that the average wind speed distribution was represented by a Rayleigh distribution, to estimate annual average capacity factor using a widely installed commercially available wind turbine (GE Energy 1.6-100) at an 80 meter hub height. The capacity factors include an adjustment to the turbine power curves to account for changes of air density. Air density was estimated based on elevation.

Project size estimates were based on an estimated potential of 1 megawatt per 100 acres of available land, with an additional assumption that only 50 percent of all available land could reasonably be developed. Additional land exclusions include:

- Areas with predicted net capacity factor below 25 percent
- Operating wind projects within WREZ zones

### References


- AWS Truepower, "New Wind Energy Resource Maps of California", available at: http://www.energy.ca.gov/pier/project_reports/500-02-055F.html
- Western Renewable Energy Zones (WREZ) Generation and Transmission Model (GTM), version 3, available at http://www.westernenergyboard.org/wieb/wrez/tool/GTMWG%203.xlsm
- AWS Truepower, LLC, "Intermittency Analysis Project: Characterizing New Wind Resources in California", available at: http://www.energy.ca.gov/2007publications/CEC-500-2007-014/CEC-500-2007-014.PDF
- US Department of Energy WINDExchange, Utility-Scale Land-Based 80-Meter Wind Maps, available at: http://apps2.eere.energy.gov/wind/windexchange/wind_maps.asp

### *Solar Thermal*

Solar thermal power output is proportional to the amount of direct normal radiation in the area, which makes availability of direct sunlight very significant. To estimate the land available in California for solar thermal development, NREL direct insolation maps were used in RETI to identify locations of greatest interest. Only grid squares with insolation greater than 6.75 kWh/m2/day were used in the analysis. Following this initial review, further exclusions were applied. The key exclusion is for land greater than 1 percent slope. Land with higher slope is considered uneconomic for solar thermal development due to the high cost of civil works required to terrace or level the land. Finally, only contiguous areas of at least two square miles were used, corresponding to a single project parcel with a capacity of 200 MW. No changes to the resource potential for solar thermal has occurred since the RETI report.

#### References


- Perez, et.al., "SUNY Satellite Solar Radiation model", available at: www.nrel.gov
- Blair, et.al., " Modeling Photovoltaic and Concentrating Solar Power Trough Performance, Cost, and Financing with the Solar Advisor Model"
- NREL Insolation Maps, available at http://www.nrel.gov/csp/maps.html
- George Simons and Joe McCabe, "California Solar Resources" California Energy Commission, CEC-500-2005-072 April 2005.
- Bureau of Land Management, California Desert District, http://www.blm.gov/ca/st/en/fo/cdd/alternative_energy.html


### *Geothermal*

An assessment of available geothermal potential for use in the RPS Calculator was prepared by GeothermEx, under subcontract to Black & Veatch for the RETI and WREZ reports. For the purposes of this study, geothermal potential has been estimated using a combination of heat-in-place analysis and geological analogy. The approach entails estimating the area, thickness, and average temperature of the exploitable reservoir in a geothermal area. The potential in megawatts (MW) is then calculated assuming a certain project life and recovery efficiency. GeothermEx has modified the approach to include probabilistic considerations to account for uncertainty in the input parameters. This probabilistic heat-in-place approach was applied in a 2004 study of the geothermal potential of California and Nevada for the California Energy Commission. This 2004 study (referred to herein as the CEC-PIER report) has been cited in several subsequent studies (such as the Western Governors' Association study of 2006 and a 2006 map of California resources by the California Geothermal Energy Collaborative). The 2004 study provides the basis for most of the MW estimates in the RETI project from 2008-2010 in California and Nevada, and the WREZ project in 2009 for other states. These assumptions were reviewed and modified slightly in this version of the Calculator to take into development that has occurred since the initial assessment.

For areas outside California and Nevada, GeothermEx has relied on published estimates of others and its own non-proprietary sources to estimate MW potentials. Most of these estimates involve geological analogy to areas that have had the benefit of more thorough exploration. For instance, regions with volcanic rocks of a certain type and age may be deemed to have a certain MW potential based on their similarity to geothermal resources that have been developed elsewhere.

### References


- GeothermEx, 2004. New Geothermal Site Identification and Qualification. Consultant report for the Public Interest Energy Research (PIER) program of the California Energy Commission (CEC). CEC Publication No. P500-04-051: http://www.energy.ca.gov/pier/final_project_reports/500-04-051.html.
- Western Governors' Association, 2006. Geothermal Task Force Report, Clean and Diversified Energy Initiative. Available at: http://www.westgov.org/wga/initiatives/cdeac/Geothermal-full.pdf.
- California Geothermal Energy Collaborative/GeothermEx, 2006. California Geo-thermal Fields and Existing Power Plants: http://ciee.ucop.edu/geothermal/documents/FinalGeothermalFactSheetAndMap.pdf.
- E3, 2014. "Capital Cost Review of Power Generation Technologies: Recommendations for WECC's 10- and 20-Year Studies." Available at: https://www.wecc.biz/Reliability/2014_TEPPC_Generation_CapCost_Report_E3.pdf
- CEC IEPR (2014): http://www.energy.ca.gov/2014publications/CEC-200-2014-003/CEC-200-2014-003-SD.pdf


## *Bioenergy*

The project identification process for biomass resource utilization focused more on available biomass fuel and less on the actual locations of specific plants. While preliminary sites have been identified for some projects, these exact locations are generally not critical to the viability of the facility.

For large scale (>20 MW) California projects, county-level information from the California Energy Commission and California Biomass Collaborative (CBC) was used as the basis for identifying the total amount of biomass that could be used for fuel for power generation. The feedstock types included agricultural residues (orchard/vineyard, field/seed crop, vegetable crop, and food/fiber), forest residues (thinnings, slash, shrub, and mill residues), and urban wood waste. After discussion with biomass stakeholders, Black & Veatch then assumed that one-third of this theoretical fuel capacity would be available for power generation. The remainder would be unavailable or used in competing markets such as for mulch, biofuels, and other purposes. Using the amount of "technically available" biomass for each category, these estimates were converted to an equivalent amount of MW potential using the CBC heating value for each fuel, a heat rate of 13,650 BTU/kWh, and an 80 an percent capacity factor. This method defined the state-wide capacity (by county) and set the basis for project identification.

The following technology assumptions were made in the characterization of large scale biomass direct-fired projects.

- Conversion Technology: Combustion of biomass fuel was assumed to take place in a stoker or fluidized bed steam generator with a standard steam power cycle. Assumed emissions control equipment included selective non-catalytic reduction (SNCR) for NOx control and a baghouse/electrostatic precipitator for particulate control. This combination represents conventional technology which has been proven over many years of operation.
- Biomass Feedstock Costs: Estimates for the cost of different biomass fuel feedstocks were developed from data supplied by the Green Power Institute, updated to current costs, and adapted for the resources identified in the CBC report. Delivered costs range from \$27 to \$48 per dry ton, depending on the resource used.

Versions 6.0 and 6.1 of the RPS Calculator also include distributed solid biomass and biogas resource potential that would be used to be compliant with the bioenergy feed-in tariff (FIT, SB 1122). Work performed by Black & Veatch that estimated the resource potential and likely compliance options by each IOU to meet SB 1122 needs was included. For small-scale biogas, food waste, leaves/grass, fats/oils/greases (FOG), and dairy manure was included as available resources up to SB 1122 procurement limits.

### References


- Milbrandt, A., 2005. “A Geographic Perspective on the Current Biomass Resource Availability in the United States.” NREL Technical Report NREL/TP-560-39181.
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- Direct discussion with the CBC and the Green Power Institute for feedstock costs
- CPUC Ruling and Black & Veatch report, “Small-Scale Bioenergy: resource potential, costs, and FIT implementation assessment” http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M081/K583/81583311.PDF


### *Solar PV – Distributed*

In September 2013, Black & Veatch completed a “Southern California DG Potential Study” to identify PV potential around key SCE 230 kV substations affected by SONGS retirement. In performing this assessment, new analysis techniques were deployed to identify potential project size and cost of energy for all parcels tied to six major substations. This included residential and commercial/industrial rooftops, along with the first widespread assessment of parking lot potential.

An expansion of this analysis was undertaken for major urban areas in the remainder of the state. Only metro areas over 400,000 residents were used, which captures the 11 largest urban areas (~20 million residents), and the majority of the potential in the Bay Area, Los Angeles, and San Diego. Non-IOU areas outside the CAISO (most notably LADWP and SMUD service territories) were excluded.

To perform this work, GIS analysis was used to identify parking lot and rooftop square footage for each commercial land parcel. The image in Figure 2420 shows an example, with rooftops in red and parking lots in blue.

**Figure 24. Example use of satellite imagery to identify rooftops and parking lots for DG potential assessment.**

Potential PV capacity was calculated from the identified square footage estimates. Discounts were applied from the theoretical potential to derive technical and developable potential, as outlined in Table 107.

**Table 10. Assumptions used to derive developable potential estimates.**

| | Parking Lots | Rooftops | Notes |
|---|---|---|---|
| Theoretical Solar Potential (acres/MWdc) | 2.5 | 2.5 | Accounts for typical development densities |
| Technical Potential (% of Theoretical) | 75% | 50% | Accounts for suitable development area (shading, skylights, etc.) |
| Developable Potential (% of Technical) | 50% | 50% | Accounts for potential participation rate |

Once developable potential estimates were created for each parcel, information on distribution system hosting capacity from utility-published interconnection maps (early 2015 vintage) was taken into account to further refine estimates and develop interconnection costs. Potential was characterized versus minimum daytime load (penetration of 0-15%, 15-30%, 30-100, >100%), with different interconnection costs as the penetration rose. Black & Veatch developed cost and performance assumptions for each potential location and then summarized the potential by metropolitan area and super CREZ.

**References**

- Southern California DG Potential Study: http://www.cpuc.ca.gov/NR/rdonlyres/3A7ADC83-6282-4E90-954D-3D4AB10770EE/0/DGResourceAssessment.pptx
- USGS High Resolution Orthoimagery retrieved from the USGS EarthExplorer site: http://earthexplorer.usgs.gov/
- Parcel data retrieved from County and/or Municipality GIS department websites (numerous)
- Land Use / Zoning data retrieved from County or Municipality GIS department websites (numerous)
- PG&E Interconnection Maps: http://www.pge.com/en/b2b/energysupply/wholesaleelectricsuppliersolicitation/PVRFO/pvmap/index.page (access request required)
- SCE Interconnection Maps: http://www.sce.com/nrc/kml/SCEGenerationInterconnection.kmz (requires Google Earth)
- SDG&E Interconnection Maps: http://www.sdge.com/generation-interconnections/interconnection-information-and-map (access request required)

# Transmission Availability & Cost

The availability and cost of transmission are primary components in the calculation used to rank competing resources. They reflect the cost to deliver new renewable generation to California loads. Data on the costs and availability of transmission fall into two primary categories:

1. **Transmission inputs provided by CAISO** based on the results of interconnection studies, the Transmission Planning Process (TPP) studies, and other work conducted by CAISO; and
2. **Conceptual transmission inputs developed by Black & Veatch** to apply in areas or regions that have not been studied by CAISO. These include costs for both in-state transmission to areas that have not been studied by CAISO as well as new out-of-state transmission to the California border.

The data and sources of information used in each of these efforts is described in more detail in subsequent sections.

## Transmission Inputs from CAISO

### *Full Capacity Deliverability Status (FCDS) Inputs*

CAISO provided cost and availability assumptions for existing transmission, minor upgrades and major upgrades to make resources fully deliverable. These inputs assumptions are provided for transmission areas, geographic areas that include one or more resource areas (SuperCREZ and/or WREZ) for the purposes of allocating fully deliverable transmission capacity.[25] The inputs provided by CAISO for v.6.1 of the RPS Calculator are summarized in Table 1110 (availability of capacity on the existing system) and Table 1211 (potential upgrades and associated costs).

**Table 11. Estimates of available FCDS capacity on the existing system provided by CAISO.**

| Transmission Area | Capacity (MW) |
|---|---|
| El Dorado | 412 |
| Greater Carrizo | 40 |
| Greater Imperial | 800 |
| Greater Kramer | 250 |
| Los Banos | 130 |
| Mountain Pass | 370 |
| Riverside East & Palm Springs | 350 |
| Round Mountain | 28 |
| Sacramento River | 37 |
| Solano | 101 |
| Tehachapi | 3,774 |
| Westlands | 1,500 |

**Table 12. Cost and capacity provided by potential transmission upgrades provided by CAISO.**

| Transmission Area | Capacity (MW) | Cost ($MM) | Associated Transmission Projects |
|---|---|---|---|
| Greater Imperial | 1,500 | $900 | IV – Salton Sea 500 kV Line |
| Greater Kramer | 760 | $436 | Coolwater – Lugo |
| Riverside East & Palm Springs | 2,000 | $955 | West of Devers |
| Riverside East & Palm Springs (#2) | 1,000 | $1,800 | Valley - Serrano No. 2 500 kV T/L; Valley - Salton Sea - Col Riv 500 kV T/L |
| Tehachapi | 1,000 | $100 | |
| Westlands | 1,000 | $175 | Gates-Gregg 230 kV line; Borden-Gregg 230 kV upgrade and SPS |

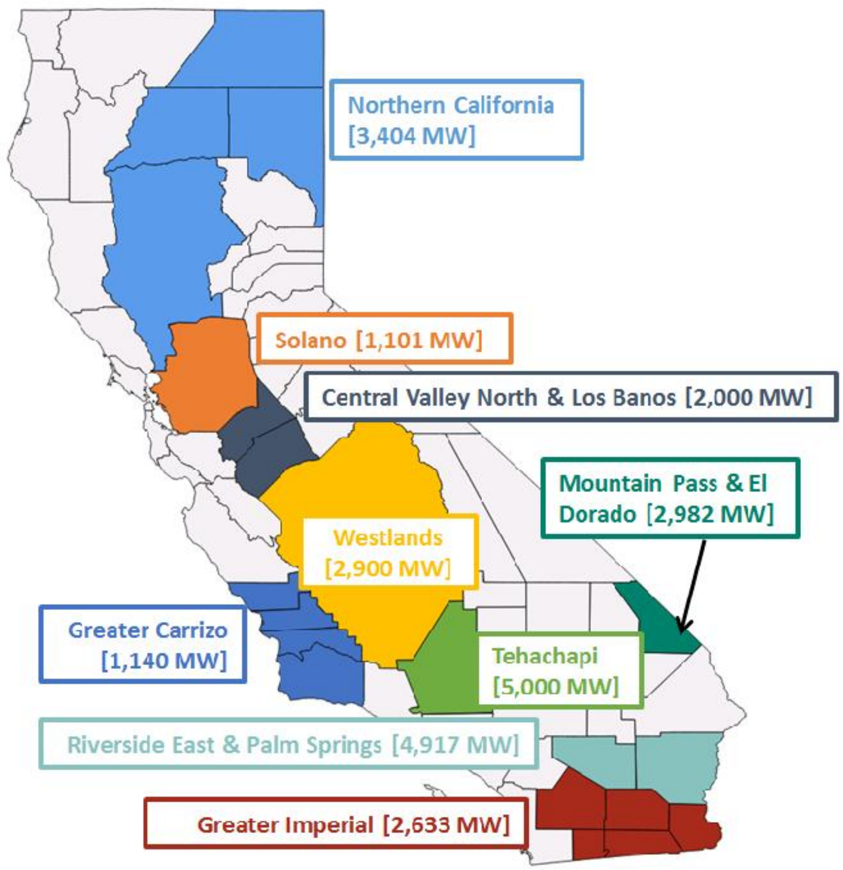
### *Energy Only (EO) Inputs*

In 2015, CAISO developed "rules of thumb" to limit the quantity of EO resources in the RPS Calculator. These inputs represent the approximate capacity available on the existing transmission system for EO resources to interconnect before significant congestion is expected to occur. These rules of thumb often

[25] In many cases, Transmission Areas correspond directly to a single SuperCREZ as identified by Black & Veatch. However, there are a number of instances where Transmission Areas include aggregations of several SuperCREZs. Examples of such aggregations include Greater Imperial (Imperial East, North & South, and San Diego South) and Greater Carrizo (Carrizo North & South, Cuyama, and Santa Barbara). A complete mapping between SuperCREZs and Transmission Areas is included in the RPS Calculator's 'Tx_Mapping' tab.

encompass multiple transmission areas – for example, CAISO estimates approximately 3,400 MW of available capacity on the existing system to accommodate EO resources in Lassen North, Round Mountain and Sacramento River transmission areas. To implement the rules of thumb, energy only zones were defined to map the appropriate transmission areas to the geography where the rules of thumb apply. Figure 2521 shows the energy only zones in CAISO and the capacity for energy-only resources on the existing system.

**Figure 25. Energy-only zones and applicable "rule-of-thumb" limits for energy only resources on the existing system.**




## Conceptual Transmission Inputs

In order to rank and select resources for a least-cost portfolio among all possible options in the Western Interconnection, additional information regarding the expected costs of new transmission investments beyond that provided by CAISO is needed. Specifically:

- **Estimates of transmission costs to California areas not studied by CAISO:** CAISO provides DNU cost estimates for those areas that it has studied through its interconnection processes and transmission planning studies, but these generally reflect a limited subset of possible areas for renewable development within the state of California.

- **Estimates of out-of-state transmission costs:** CAISO does not provide any information on the cost of potential new transmission that would deliver resources from outside of California to the California border.

In order to supplement the assumptions provided by CAISO with these two additional necessary pieces, Black & Veatch developed cost estimates for generic transmission investments both within and outside of the state of California. Because these transmission cost estimates are developed using generic transmission cost assumptions and are not associated with specific proposed projects, they are described as "conceptual" transmission costs.

In order to develop conceptual transmission costs for California areas that have not been studied by CAISO in its planning processes, Black & Veatch uses the following assumptions:

- Single circuit 500 kV AC line to major load substations in Northern and Southern California
- The costs are based on the final 2015 CA PTO unit cost estimates and include the line, necessary substations, and right of way

Conceptual costs for out-of-state transmission projects that would deliver remote resources to the California border are largely based on Black & Veatch's estimates developed to inform the transmission planning studies of the WECC. Given the size and magnitude of new out of state projects being proposed, the Calculator assumes that no existing transmission is available (e.g., new transmission must always be built). Out-of-state energy is delivered to in-state "gateway CREZs" based on routing from the WREZ Generation and Transmission model. Transmission costs from out-of-state CREZs were estimated using both assumptions for AC and DC circuits; for each out-of-state resource area, the lower cost option is specified in the Calculator. For AC lines, the assumptions are that the line is a 500 kV single-circuit ac, 1500 MW capacity, $2.0 million/mile (2015 dollars). For DC lines, the assumptions are that the line is a +/- 600 kV bipole circuit, 3000 MW capacity, $1.6 million / mile, with a 600 kV HVDC converter station ($517 million). Lines longer than 600 miles are more likely to be DC based on economics and lower losses.

### References


- CAISO Participating Transmission Owner Unit Cost Estimates: http://www.caiso.com/informed/Pages/StakeholderProcesses/ParticipatingTransmissionOwnerPerUnitCosts.aspx
- CAISO Transmission Planning Process https://www.caiso.com/planning/Pages/TransmissionPlanning/Default.aspx
- Capital Costs for Transmission and Substations, Updated Recommendations for WECC Transmission Expansion Planning (February 2014) http://www.wecc.biz/committees/BOD/TEPPC/External/2014_TEPPC_Transmission_CapCost_Report_B+V.pdf.